JOURNAL

OF THE

FRANKLIN INSTITUTE

OF THE STATE OF PENNSYLVANIA

FOR THE PROMOTION OF THE MECHANIC ARTS

VOL. CLIX, NO. 5 80TH YEAR MAY, 1905

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Mechanical and Engineering Section.

Stated Meeting, held Thursday, January 18, 1905.

Steam Turbines.

Discussion opened by PROF. H. W. SPANGLER.

PROF. SPANGLER.—Ordinarily, in estimating the value of a comparatively new piece of apparatus, there are some considerations in favor of and some opposed to the introduction of such apparatus. It is not often that the considerations on one side so strongly outweigh those on the other as is the case with the steam turbine.

The advantages claimed for steam turbines are many and the statement of a few of them may be of interest.

One generally considers the question of the steam economy of the turbine as compared with that of a steam engine as one of great importance. As much of the available data is difficult to compare, its discussion will be taken up later.

In addition to the steam economy, some of the advantages claimed for a steam turbine may be stated. The smaller size and weight of the steam turbine for the same output and the absence of reciprocating parts, make a unit requiring much less foundation, thereby materially reducing the cost of the installation.

You are all familiar with the drawing showing the relative space occupied by a Parsons Turbine and by a reciprocating engine unit of the same output. This comparison applies equally well to other applications of turbines.

I exhibit herewith some lantern photographs*

The first shows two pumps located in the coal mines at Bruay, in Northern France. These are fly-wheel condensing pumps, two complete pumping plants using the same fly-wheel. The space occupied is about 93 feet long, 28 feet wide and 19.7 feet high, with a foundation extending 13 feet below the pumps.

The second is a cross-section of the compartment showing that the side walls required were 6½ feet thick.

The third shows a turbine pump installed at the same place, the output of this pump being the same as that of one of the pumps in the previous diagram. The space required is 29.5 feet, by 10.4 by 13.1 feet, the side walls being 2.3 feet thick, the foundation being little more than a good floor.

The cost of two turbine pumps installed is less than one-half the cost of the two reciprocating pumps installed shown on slides 1 and 2.

A turbine pump supplying 2000 h. p. with feed water will occupy much less than half the floor space of a reciprocating pump of the same capacity.

The few bearings requiring lubrication in the majority of turbines and the ease with which the lubrication can be effected and controlled, and the fact that no oil need be used with the steam reduces the operating costs materially.

The ability to use high superheat, which is a particularly advantageous feature of some turbines, and to a less degree of others, should reduce the coal consumed, and the fact that the difficulties met with in using highly superheated steam in reciprocating engines are not met with in turbines, or to a lesser

*From Circular of Compagnie des Mines de Houille de Bruay, 1904.

degree, has resulted in the use of superheaters in many turbine plants.

The few bearings in a turbine outfit as compared with the many in a reciprocating one, the absence of sliding surfaces as piston, crosshead, valve mechanism, tend to a substantial decrease in operating expenses, and from such data as are available, this result is attained in practice.

The price one has to pay for a turbine set is large. Whether the increased price is justified must be determined for each case independently. Some recent figures on a plant of 1500 K.W. actual bids gave the cost of a reciprocating engine outfit from 25% to 50% less than the cost of turbine outfits, Three other bids on turbine units of 1500 h. p. varied about 24% among themselves.

It is probable that the difference in price between turbine and reciprocating engines will more nearly vanish as the making of turbines become standardized, and, in such sizes as are now standard, prices are as low or lower than for competing reciprocating plants.

To return to the question of efficiency, it seems reasonable to expect the efficiency of a turbine unit will be maintained with less difficulty than that of a reciprocating one. Turbine tests, repeated after a reasonable length of time, have given results practically the same as at the beginning. While this can be said of steam turbines, identically the same can be stated of reciprocating units that have been properly taken care of. It is, nevertheless, true that it requires less money to keep a turbine plant up to its initial efficiency.

This brings me to the question of efficiency that I would like to discuss at some length. Our ordinary conception of efficiency is either hazy or inexact. The off-hand statement that one machine develops a horse power on 15 lbs. of steam while another does it on 14 lbs, may be true and the second may be the more efficient of the two. One machine uses steam of higher pressure than the other, and this makes much less difference in the steam used per h. p. than is ordinarily supposed; or another works to a slightly greater vacuum, which makes much more difference than is usually supposed. Or it may be one used superheat of a greater amount than another. A rational basis for comparing two different types of machines is not easy

to reach. The output of the machines divided by the heat available in the coal is fair *for the entire plant*, but when it comes to one portion of the plant, such as the prime mover, the comparison is not a fair one. The basis which is used here is the one which is coming more and more into use, and eliminates boiler, superheater, feed water heater, &c., and puts the output of the machine against the maximum amount of energy available between the conditions under which the steam is received by and discharged from the engine.

In Table I are the results of many tests made on steam engines. The headings of the table, until we come to those headed E, &c., are clear. The various engines are arranged with increasing value of E_5* This column is a measure of the amount of coal that would be used to run the engine if equally efficient apparatus, excluding the engine, was used in each instance, and is a fair measure of the value of the engine from the operator's standpoint, as it takes account of the conditions under which it is operated. The general range of the figures are worth noting. They increase continuously from the lowest to the highest, which is practically .21, without any very

*The columns headed E_1, E_2, etc., are determined as follows: E_1, is Carnot's efficiency or $\frac{T_1-T_2}{T_1}$ where T_1 is the highest absolute temperature of the steam, and T_2 is the lowest. The number represents the maximum quantity of work that any ideally perfect engine could convert into work for 100 heat units supplied the engine.

The steam engine does not even theoretically act as the ideally perfect engine, and should convert into work, theoretically, the quantity shown under E_3. The value of the scheme and conditions under which the engine works (including pressure, superheating, vacuum, etc.) is shown by E_2 which is $\frac{E_2}{E_1}$. The value of E_3 is derived from the equation

$$E_3=\frac{\gamma_1+C_p\,(T_3-T_1)-\left[q_2+T_3\left(\int_1\frac{cdt}{T}-\int_1\frac{cdt}{T}+\frac{r_1}{T_1}+C_p\,log_e\,\frac{T_3}{T_1}\right)\right]}{\gamma_1+C_p\,(T_3-T_1)-q_2}$$

if the steam is superheated as it enters the engine and not superheated as it leaves.

If the steam supplied the engine is dry saturated, all terms containing C_p drop out. If the steam supplied is wet, so that x parts are steam and $1-x$ water, instead of $\frac{r_1}{T_1}$ read $\frac{xr_1}{T_1}$ and instead of γ_1, read q_1+xr_1, and omit all terms with C_p.

In this formula γ_1, is the total heat required to form steam at the pressure under which it is supplied (taken from the steam tables.)

great break. A comparison of this column with that marked steam per H.P. hour shows that for wide difference of E_5, the amount of steam per h. p. hour varies inversely with the value of E_5, while for small differences in E_5 this is not so, and the coal cost per H.P. may be less with the greater steam consumption.

While this value E_5 may be called the relative value to the consumer, the value of the machine as an apparatus for turning heat into work is more nearly represented by the column E_4, which shows the percentage of the available heat actually appearing as work.

For steam engines generally the difference between this figure and 100 is understood to be accounted for by initial condensation, by the passing of steam through the cylinder without doing any useful work. The value of this initial condensation is given, in some cases, in the column headed "Per-

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$C_p = .462 + 0.001525p$, p being the absolute pressure. $T_3 - T_1$, is the amount of superheating. q_2 is the heat in 1 pound of water at the temperature T_2 corresponding to the back pressure.

$\int_1 \frac{Cdt}{T}$ is the entropy at the pressure of the steam.

$\int_2 \frac{Cdt}{T}$ is the entropy at the exhaust pressure.

r_1 is the latent heat at the steam pressure.

T_3 is the absolute temperature of the superheated steam. T_1 is the absolute temperature of saturated steam corresponding to the pressure.

All heat quantities and entropy are measured from 32°F. E_5 is the actual work done by each 100 heat units supplied the engine. Its value is found from

$$E_5 = \frac{2545}{W\,(\gamma_1 + C_p(T_3 - T_1) - q_2}$$

Where W is the number of pounds of steam per indicated horse power per hour.

E_3 is what we ought to get from 100 heat units supplied and E_5 is what we do get and the efficiency of the heat transformation $E_4 = \frac{E_5}{E_3}$

Taking any one line of values for an example, we have

24.08, 94.5, 22.73, 53.5, 12.17

An ideally perfect machine could give for each 100 heat units supplied 24.08 [E_1] heat units as work. The scheme adopted for the given engine is only 94.5% [E_2] as good and if it worked perfectly as intended and under the conditions we have imposed on it, it should return 22.73 [E_3] heat units as work. Instead of working as well as the conditions imposed will allow, it only works 53.5% [E_4] as well and actually returns only 12.17 [E_5] heat units.

STEAM TURBINE TESTS

TURBINE	1 H.P. K.W.	Steam per 1 H.P. K.W.	Steam Press. Absolute	Vacuum	Sat. or Super-Heated	E_1	E_2	E_3	E_4	E_5	G	Expansion	Revs.	AUTHORITY
DeLaval	B.H.P. [16.1] 14.5	B. [61.6] 68.5	110	0 in.	Sat.	15.3	90.8	13.9	29.7	4.13	24.1		10200	A.S.M.E. Vol. XVIII 1897, p. 700
DeLaval	B.H.P. [49.0] 44.1	B. [35.0] 38.9	103	0 in.	Sat.	14.9	95.3	14.2	51.2	7.26	41.4		20000	Engrg. News, Apr. 17 1902, p. 318
DeLaval	B.H.P. [57.7] 51.9	B. [22.74] 25.3	103	0 in.	605°	27.85	64.9	18.07	45.	8.14	36.5		20000	Ditto
Parsons 500 K. W.	K.W. [858] 518	K.W. [15.12] 25.0	148	27.8 in.	Sat.	30.8	90.1	27.75	54.3	15.06	43.9		——	Electrician Oct. 23, 1903, p. 22
DeLaval 300 H. P.	E.H.P. [346] 281	B. [12.90] 14.33	212.9	27.08 in.	Sup. 60°F	36.4	78.9	28.7	59.9	17.18	48.5		Dyn. 736.9	Electrical Age July, 1902, p. 157
Westinghouse Parsons 750 K. W.	E.H.P. [1254] 1015	E.H.P. [12.95] 16.01	155	28.33 in.	x=.98	32.4	92.8	30.1	57.4	17.23	46.4		1800	Engineering Record Nov. 5, '03, p. 550
Curtis 500 K. W.	K.W. [847] 512	K.W. [12.45] 20.6	168	26.9 in.	Sup. 104°	37.9	72.1	27.3	63.4	17.31	51.4		1820	Engineering Nov. 18, 1904, p. 679
Westinghouse 400 K. W.	[663] 400	E.H.P. [13.2] 16.4	126	26 in.	Sat.	27.1	90.6	24.5	72.1	17.6	58.4		——	Engineering News Oct. 20, 1902, p. 372
Curtis 750 K. W.	[1242] 750	K.W. [12.03] 19.9	140	28 in.	Sup. 100°	38.4	64.4	28.2	63.2	17.95	51.2			Electrician Oct. 23, 1903, p. 19
Rateau 525 E. H. P.	E.H.P. [649] 525	E.H.P. [12.77] 15.75	135	26.76 in.	Sat.	28.6	90.9	26.0	69.6	18.1	56.4		3000?	Engineering Magazine Oct. 1903, p. 57
Parsons 300 K. W.	K.W. [516] 312	K.W. [12.1] 20.06	165	27.8 in.	Sup. 33.3	35.9	80.6	28.9	62.7	18.1	50.8		3000	Electrician Oct. 23, 1903, p. 19
Parsons 500 K. W.	[831] 501.9	[11.77] 19.47	160	27.4 in.	Sup. 93°	37.65	74.2	27.9	65.8	18.38	53.3		3000	Same
Zoelly 500 H. P.	[645] 389.6	[11.1] 18.39	181.8	28.8 in.	Sup. 122°	42.9	73.1	31.35	59.3	18.59	48.		2073	Stodola, p. 208
Rateau 500 E. H. P.	E.H.P. [617] 500	E.H.P. [12.56] 15.5	120.	26.74 in.	Sup. 10°	28.6	84.6	24.2	77.0	18.6	62.3		3000?	Engineering July 17, 1903, p. 105
Parsons 900 K. W.	K.W. [1485] 897.	K.W. [10.7] 17.73	160.	26.5 in.	Sup. 2.37	45.2	62.0	28.0	66.9	18.72	54.2		1710	Electrician Oct. 23, 1903, p. 22
1360 K. W. Reidler-Stumpff	[2260] 1365	[11.89] 19.66	188.5	25.62 in.	Sat.	29.5	78.4	23.1	84.5	19.5	68.4		3000	Stodola, p. 198
Westinghouse 1250 K. W.	[2142] 1294	[11.17] 18.48	161.0	27.1 in.	Sup. 76	36.1	76.4	27.55	71.2	19.6	57.6		1200.6	Engrg. Record Feb. 20, '04, p. 232
DeLaval 150 H. P.	B.H.P. [181] 163	B. [15.8] 17.6	128.5	26.4 in.	Sat.	27.9	90.	25.1	78.3	19.67	63.5		——	Electrician Oct. 23, '03, p. 19
Westinghouse 1500 K. W.	E.H.P. [2495] 2023	E.H.P. [11.32] 13.99	164.1	27.5 in.	x=.994	31.	90.	27.9	72.5	20.2	58.7		1456	Soc. Nav. Engrs. Nov. 1903, p. 1252
Westinghouse 1250 K. W.	K.W. [2110] 1274	K.W. [10.67] 17.66	160.7	28.1 in.	Sup. 78.25	37.9	76.3	28.9	69.9	20.18	56.6		1199.4	Engrg. Record Feb. 20, '04, p. 232
Curtis 2000 K. W.	[3760] 2270	[9.79] 16.2	115.	28.1 in.	Sup. 250°	46.5	61.3	28.4	71.6	20.38	58.0		750	Engineering July 11, 1904, p. 100
Brown-Boveri (Parsons) 1400 K. W.	[2385] 1440	[9.61] 15.9	171.	28.8 in.	Sup. 118°	42.4	57.1	24.2	89.3	21.6	72.3		1500	Electrician April 29, '04, p. 44
Brown-Boveri (Parsons) 3000 K. W.	[5570] 3364	[9.67] 16.0	183.7	27.0 in.	Sup. 75°	36.6	67.6	28.4	79.5	22.55	64.4		1269	Tests made at Milan May, 1903.

STEAM ENGINE TESTS

ENGINE	H. P.	Steam per I. H. P.	Steam Pressure Absolute	Vacuum	Sat. or Sup.	E_1	E_2	E_3	E_4	E_5	Expansion	% Initial Condensation	Missing Quantity	Revs.	AUTHORITY
Westinghouse Standard 9.5 and 9.5 by 9	44.8	32.6	106.4	0 in.	Sat.	15.13	93.7	14.16	55.1	7.8	2.305	29.7	434	352	Barrus Engine Tests 16 A page 85
Balanced Slide Valve 18 in. by 30 in.	209.1	28.93	82.3	0 in.	Sat.	13.15	93.8	12.34	71.4	8.82	2.415	18.	1088	164.4	Barrus Engine Tests 17 B page 88
Centre Valve Engine 14 in. by 6 in.	31.6	26.81	111.8	0 in.	Sat.	15.55	85.8	13.33	71.0	9.46	3.85	24.8	211	400.9	Willans—Inst. Civil Engineers Vol. XCIII p. 164
Corliss (Reynolds) 18.02 in. by 48 in.	137.0	25.9	107.2	0 in.	Sat.	15.13	93.7	14.16	69.3	9.81	6.25	26.7	947	75.3	Hill—Millers' Exhibition Cincinnati, 1880
Wheelock 18.26 in. by 48 in.	140.0	24.9	106.2	0 in.	Sat.	15.13	93.7	14.16	72.0	10.19	5.88	20.5	715	76.1	Same
Corliss (Harris) 18.03 in. by 48 in.	134.3	23.9	106.2	0 in.	Sat.	15.13	93.7	14.16	75.2	10.64	7.35	24.7	793	75.8	Same
Balanced Slide Valve 18 in. by 30 in.	213.2	22.08	81.7	25 5 in.	Sat.	23.64	92.4	21.83	48.8	10.67	3.34	23.0	1083	165.6	Barrus Engine Tests 17 A page 88
Willans 10 and 14 in. by 6 in.	30.	23.0	105.0	0 in.	Sat.	15.77	94.6	14.9	74.	11.03	4.0	6.23	43.0	401.5	Inst. Civil Engineers Vol. XCIII p. 166
Corliss 20½ and 20½ in. by 4 ft.	210.5	21.11	81.9	26.2 in.	Sat.	24.4	92.5	22.6	49.4	11.1	6.14	35.6	1576	60.3	Barrus Engine Tests No. 3 A page 49
Four Valve 34 7-16 in. by 5 ft.	613.4	18.49	97.0	27.9 in.	Sat.	28.1	91.5	25.7	44.3	11.36	5.32	33.1	3756	59.9	Ditto No. 22 p. 103
Same as No. 4.	162.3	20.6	107.2	25.5 in.	Sat.	25.45	91.7	23.3	48.9	11.38	8.06	27.7	927	75.4	
Westinghouse 16 and 27 in. by 16 in.	225	21.07	140.0	0 in.	Sat.	17.32	93.3	16.15	74.4	12.00	——	——	——	240.	Test by Author 1901
Same as No. 6.	165.6	19.4	106.4	25.7 in.	Sat.	25.84	91.5	23.63	51.0	12.06	8.40	28.9	927	75.8	
Donkin Pumping 16 17 32 and 30 in. by 3 ft.	87.03	19.22	66.7	27.3 in.	Sat.	26.83	90.7	24.3	51.0	12.38	——	——	——	55.3	Proceedings Inst. Civil Engineers Vol. LXVI p. 278
Willans 10 and 14 in. by 6 in.	40.03	20.75	149.8	0 in.	Sat.	17.83	93.3	16.63	73 1	12.14	4 46	8.9	74.6	406.8	Inst. Civil Engineers Vol. XCIII p. 172.
Same as No. 5.	158 4	19.5	106.1	24.0 in.	Sat.	24.08	94.5	22.73	53.5	12 17	7.64	28.7	888.	74.5	
Westinghouse 12 and 20 in. by 12 in.	228.3	18.92	144	25 in.	Sat.	26.83	90.7	24.3	51.	12.38	4.27	19.6	840	300.	Barrus Engine Tests No. 33 A page 136
Harrisburg Tandem 17 and 28 in. by 22 in.	311.3	19.79	134	0 in.	Sat.	17.82	92.8	16.52	77.2	12.73	——	——	——	179.1	Tests by Author 1901
Willans 10 and 14 in. by 6 in.	45.3	19.18	176.9	0 in.	Sat.	19.1	93.	17.76	73.7	13.09	5.57	13.3	113.7	421.7	Inst. Civil Engineers Vol. XCIII p. 184
Willans 7 and 10 and 14 in. by 6 in.	40.04	18.7	186.7	0 in.	Sat.	19.6	92.	18.03	74.4	13.40	——	10.32	773.	414.9	Same Vol. XCIII p. 170
Holly Pumping 36 and 62½ and 92 in. x 60 in.	898.	14.64	157.	25.5 in.	Sat.	28.05	90.3	25.33	62.9	15.92	——	——	——	21.08	Tests by Author 1896
Corliss 24 and 44 in. by 60 in.	872.9	14.18	130.1	28.4 in.	Sat.	31.2	90.4	28.2	56.6	15.95	9.79	13 14	1656.	71.3	Barrus Engine Tests No. 49 p. 196
Leavitt Pumping 25½ and 52 in. by 48 in.	251.5	13.9	114.1	28.1 in.	Sat.	29.7	90.3	26.8	61.2	16.39	——	——	——	13.17	Leavitt—Boston Society Civil Engineers, 1885
Southwark Vertical 13½ and 21½ and 36 in. x 30 in.	57.44	13.75	189.5	26.3 in.	Moisture 1.4 %	30.2	89.7	27.08	62.0	16.75	——	30.4	——	157.4	Tests by Author 1894
Southwark Pumping 37 and 62 and 96 in. by 54 in.	1013.5	13.8	159.1	24 in.	Sat.	26.93	91.3	24.56	69.5	17.04	——	——	——	22.46	Tests by Author 1896
Corliss 22 and 44 in. by 60 in.	636.5	13.28	130.8	25.5 in.	Sat.	20.55	90.4	26.7	64.7	17.25	15.03	21.1	1780.	68.08	Barrus Engine Tests No. 34 p. 140.
24 and 48 in. by 48 in.	858.1	13.01	137.7	28.0 in.	Sup. 7.5°	32.0	87.3	27.93	62.3	17.4	——	——	——	100	A. S. M. E. Vol. X p. 665
Same	1076.4	12.76	137.6	27.1 in.	Sup. 20°	30.8	85.8	26.4	67.5	17.8	——	——	——	100	
Nordberg Pumping 21 and 37 and 55 in. by 48 in.	509.8	12.74	124.5	26.54 in.	Sat.	27.7	90.9	25.2	72.1	18.2	——	28.0	——	39.85	A. S. M. E. Vol. XXI p. 1018
Corliss 28 and 48 and 74 in. by 5 ft.	573.7	12.55	140.3	25.3 in.	Sat.	27.15	91.0	24.7	75.5	18.63	21.1	24.4	1786.	20.99	Barrus Engine Tests No. 60 p 241
Allis Pumping 30 and 54 and 80 in. by 64 in.	548.7	11.65	151.0	26.8 in.	Sat.	31.60	86.9	27.43	71.4	19.6	24.1	——	——	16.44	Laird A. S. M. E. Vol. XXI p. 327
Dujardin 19.25, in. 29.8, 49.2 by 53.1 in.	841.8	11.08	157.7	27.38 in.	Sup. 86°	37.1	73.8	27.33	71.7	19.6	——	——	——	67.11	L'Eclairage Electique Jan. '02, p. 14
Sulzer Horizontal 30, 44.5, 2–51.6 in. by 78 in.	1870.	11.302	155.4	27.2 in.	Sat.	30.2	90.3	27.3	74.	20.28	——	——	——	56.21	A. S. M. E. Vol. XVIII p. 805
Sulzer Horizontal 20.5, 31.5, 47.25 in. by 55.2 in.	683.	10.75	168.9	27 6 in.	Sup. 17.2°	32.7	86.1	28.13	74.5	20.97	——	——	——	65.56	A. S. M. E. Vol. XVIII p. 810
22.2, 31.4, 45.2 in. by 53.9 in.	816.1	10.29	156		Sup. 179.1°	Feed temperature 50° C								70.42	Bul. Soc. Mulhouse Vol. LXVI, 1896, p. 339
Westinghouse Compound 16 and 27 in. by 16 in.	225.	21.07	140	0 in.	Sat.	17.32	93.3	16.15	74.4	12.00	——	——	——	240.	Tested by Author and showing variation of efficiency with variation in load.
Same	182.1	21.12	140	0 in.	Sat.	"	"	"	74.1	11.96	——	——	——	241.4	
Same	139.4	24.02	140	0 in.	Sat.	"	"	"	65.1	10.50	——	——	——	241.8	
Same	80.3	28.53	140	0 in.	Sat.	"	"	"	50.5	8.15	——	——	——	243.5	
Harrisburg Tandem 17 and 28 in. by 22 in.	311.3	19.79	134	0 in.	Sat.	17.82	92.8	16.52	77.2	12.73	——	——	——	179.1	Ditto
Same	238.8	21.09	134	0 in.	Sat.	"	"	"	72.4	11.95	——	——	——	180.3	
Same	156.6	24.88	134	0 in.	Sat.	"	"	"	61.4	10.13	——	——	——	180.7	
Same	93.0	32.30	134	0 in.	Sat.	"	"	"	47.5	7.8	——	——	——	180.7	

cent. of Initial Condensation." As a heat machine, therefore, the steam engine turns into work approximately 60% to 75% of the available energy, a large proportion of the balance being accounted for by the alternate condensation during admission and evaporation during the exhaust which goes on in every cylinder.

Referring now to Table 2, we have similar data for turbines of varying sizes. There are several things of note on this table; first the recent dates at which these data have been obtaind; secondly, the large number of experiments with superheat, as compared with the few in the steam engine table; thirdly, in the column E_5 the high range of values and the very few falling below 17%. A word of explanation as to the make-up of these tables. All data in parenthesis are based on the assumption of 90% mechanical efficiency and 90% electrical efficiency in the apparatus, or a total of 81% from what might be called the indicated power and the electrical output. This was done to bring the results to exactly the same basis for comparison.

The equivalent water consumption per I. H. P. is calculated, and is low as compared with steam engines of the same size and working under nearly the same conditions.

The value of E_4 does not differ very much from that for steam engines, and the fact that the metal parts of a turbine are not alternately heated and cooled does not seem to lessen greatly the loss which in reciprocating engines we attribute to initial condensation.

The reason for the high economy with steam turbines seems to be, first, the use of generally higher pressure; secondly, the use of superheated steam, both of which seem to be of less value than is usually attributed to them; and thirdly, the increased vacuum. The first condition would have the same effect both theoretically and practically in a reciprocating engine; the second theoretically is equally valuable in a reciprocating engine, but the practical use of superheat causes much trouble from variation of temperature, difficulty in lubrication and similar troubles; the third (low vacuum), theoretically is much less valuable in a reciprocating engine than in a turbine, because of the limited number of expansions valuable in the same engine.

To recapitulate:—The turbine occupies less room, requires

less foundation, and can be operated with less lubrication and as little or less attendance. It is as efficient as steam consumption from a theoretical standpoint as well as from the owner's standpoint. Its depreciation should be as small or smaller than a reciprocating unit of the same size. The increased cost at present for the largest sizes will, in many cases, be justified, and the cost will certainly become as low as, or even lower than reciprocating engines, as the machines become standardized.

PROF. LOUIS C. LŒWENSTEIN:—In the present state of steam turbine building we must give most weight to the discussion of the scientific principles involved in this important type of motor. We engineers of course know that machine building, though widely extended practical experimenting has solved problems, with the utmost ease, which baffled scientific investigation for years. But this "cut and dry" method, as engineers ironically term it, is often extremely costly; and one of the most important questions of all technical activity, that of efficiency, should lead us not to underestimate the results of scientific technical work, particularly in such new territory as this.

Time and again it is urged that machine building be placed upon a practical experimental basis. Such a beginning would not be impossible, but it also would not be economical, and therefore not technical. Industry cannot be without scientific co-operation, not from idealism, but because under certain circumstances it is a "cheapest method" of accomplishing our purpose. We may call attention to the considerable sacrifices which engineers and machine builders have made in vain, due to incomplete understanding of the scientific principles involved in the problem undertaken. The great majority of those concerned will witness with indifference the economic loss of one of their number conducting a fruitless experiment, but to thoughtful men such an occurrence, which is unfortunately only too frequent, is regarded as a common loss, even without considering the fact that no one would like to be placed in a similar position. Steam turbine building especially affords numerous examples of the necessity of combining constructive ability with scientific principles. For instance, we might refer to the importance of previously determining the exact dimensions of a rotating wheel whose periphery almost reaches the velocity of a bullet, in order that the existing stress

in the material do not at any place exceed the allowable limits Or, again, how disadvantageous it would be in the case of the horizontally rotating disc wheels that have lately come into use, and whose diameters attain considerable dimensions, to determine, experimentally, after first constructing, how much the discs deflect on account of their own weight, and how much they again straighten out, due to their centrifugal force; the latter a point of great importance, if we consider the scraping of the blades in the narrow clearance. What dangers the designer risks when he attempts the building of steam turbines without having exact knowledge of the phenomena of the so-called critical velocity. Finally, we could ask is it "economical" to even apply for a patent for a certain turbine system in which the greater part of the attainable work is destroyed before the steam has even reached the rotating wheel?

Obviously, on the other hand, we should not expect of the busy engineer in practical life that he should closely follow the complicated details of scientific work, but the fact still remains that he must be informed as to the results of scientific investigation. The intense competition to be expected between the various systems permits us to say that the designer, through the force of circumstances, is compelled to strive for the highest degree of practical and scientific perfection, in order to insure every possible success.

Within the space of a few minutes allotted to this paper we can only enter into a discussion of one of the scientific features of steam turbine design, but before doing so we might just mention a number of very important scientific investigations that must be made by the designer. The mere mentioning of these subjects will be sufficient, for their importance will be readily appreciated. Among these may be mentioned the flow of steam through orifices, nozzles and blade channels; the friction of rotating discs in a steam medium; mass balancing and the theory of the flexible shaft; critical velocity and period of oscillation due to elasticity; the deviation of rotating discs due to the bending of the shaft; the deflection of horizontally rotating discs and the action of centrifugal force upon them. We might multiply these subjects greatly, but enough are mentioned to show how necessary theoretical knowledge is to the designer of this important type of motor.

It is well known if steam, or in general any elastic fluid, flows through a simple orifice from a space of higher into one of lower pressure, the pressure in the orifice will decrease to about one-half the initial pressure, and there will occur in the stream after leaving the orifice strong accoustic vibrations. These vibrations cause a considerable loss of efficiency, and they must be avoided. De Laval has accomplished this by adding to the orifice a conically diverging nozzle in which the steam can continuously expand down to the back pressure.

Before the design of the nozzle can be undertaken we must fully understand the flow of steam in nozzles. Experiments were made to investigate this flow, and it would be well to describe briefly how they were conducted and the results derived.

An orifice of a nozzle through which the flow of steam was to be investigated was so mounted that a thin measuring tube could be inserted through the center of the opening. One end of this measuring tube was closed and the other end was connected with a pressure gauge. In the middle of this tube a hole is drilled at right angles to the axis. By means of a micrometer screw this tube can be moved in one direction or the other, so as to bring the measuring opening in any position of the nozzle axis. Experiments were first made to ascertain how reliable this method would be for the measurement of pressure, for as can be seen, it is not sufficient to place a measuring opening tangential to the flow of steam, but the position and the condition of the edges of the opening may be responsible for a disturbing effect. These experiments showed, however, that the readings taken in this manner could not materially differ from the true pressure. By now allowing steam to flow through orifices and nozzles of various shapes it was possible to plot a curve of pressures showing the variation of pressures throughout the length of an orifice or nozzle, and even beyond it. Some very interesting and important results were obtained.

The resistance to steam flow was first investigated, and after a great many experiments were made the conclusion was reached that it is allowable to consider the resistance to steam flow in a diverging nozzle as simple tube friction. With nozzles of small divergence and less than 2″ long and about ¼″ minimum diameter the loss of energy was about 10%, and with nozzles of greater divergence and about 4″ long and ⅜″ mini-

mum diameter the energy loss was 15%. The decrease of velocity is about half as great.

Through partly closing a valve placed between a nozzle and a condenser we can produce any desired back pressure. In measuring the pressure in various parts of the nozzle we would note that the pressure first follows the line of free expansion and then increases according to the value of the back pressure in more or less sudden leaps. In these extraordinary heavy increases of pressure we find a realization of the theoretically derived "Compression Shock" of von Riemann. The steam particles possessed of great velocity strike against a slower moving steam mass and are therefore compressed to a higher degree. Such compression shocks will always occur when the nozzle has a greater length; that is, a larger cross-section divergence than the initial and the final pressures demand.

Other experiments were made on the flow of steam through orifices. These experiments gave the desired explanation of the so often spoken of phenomena of flow from orifices. As is known, Messrs. Mack and Emden have proved by means of photographs the presence of regular successive light and dark lines in a steam flowing from an orifice, which cannot be said to be anything else but acoustic waves; but as to the value of the existing pressures in this stream we were totally in the dark. Emden assumes that at places of compression the same condition exists as in the orifices. But he further says in contradiction to himself that there exists the same pressure at every place in the steam as exists in the surrounding atmosphere, and claims that there is a change of density. According to this for instance, for air, places of smallest velocity, that is smallest energy, must coincide with places of smallest temperature, that is, smallest potential energy, which is obviously impossible. By his calculation he further believed to have proved that the difference between the initial and the orifice pressures can only be used to produce the additional velocity of flow; the remainder of the available work is transformed into acoustic energy. The experiments lately made by Professor Stodola contradict these opinions; they prove that the steam first expands to the existing pressure before the orifice, that therefore the first rush (as is the case with suddenly releasing a compressed spring) too much potential energy is changed into kinetic energy. Only

this excess changes into acoustic vibrations and is rechanged into heat at the rim of the stream by friction and eddy currents. The oscillations occur in the axial direction as well as in the radial. The stream flows at the pressure of the orifice into a region of much smaller pressure, begins therefore to expand in a radial direction. The resulting drop of pressure accelerates the particles also in the axial direction. Steam flowing from a diverging nozzle shows the same phenomena as from a simple orifice. With varying back pressure it was found that the steam on leaving the nozzle gave very regular acoustic vibrations, but it was possible to so fix the back pressure that every trace of a vibration disappeared.

From these experiments we finally arrive at the fact that the steam in a nozzle expands nearly adiabatically independent of the back pressure. If the steam flows into a place in which a back pressure exists exactly equal to the final pressure of expansion then the pressure in the stream is not changed at all. If the pressure is lower, acoustic vibrations occur, as with a simple orifice; if the back pressure is too high, a steam shock occurs with more or less drawn out oscillations. By entirely filling out the cross-section of a diverging nozzle, a vibration is made difficult, if not entirely impossible. We can hardly go wrong if we say that the drawn-out vibrations occurring in a simple orifice are caused primarily by the sudden difference of pressures at the stream's rim and the surrounding atmosphere, which the stream quickly spreads. There is, therefore, the possible assumption that when vibrations still occur in the interior of the nozzle, the stream has detached itself at such places from the wall.

If we construct the nozzle according to the formula of Zeuner, the final pressure will be greater than the prescribed back pressure, because friction transposes the kinetic energy into heat, and the expansion line will rise above the adiabatic. A nozzle calculated therefore according to Zeuner would actually be somewhat too long. This fact was soon recognized. To correct this Rateau, and after him Delaporte, proved by experiments that the pressure of a stream on blades or suitable plates decreased very little if the nozzles were made shorter; that is, the stream is allowed to flow out at a slight overpressure, and recommended this to be done. It remained for

Stodola to prove by his experiments just mentioned that violent acoustic vibrations would then take place in the stream, and that these must be avoided. It is important to make the nozzle dimensions suitable to the assumed back pressure. Before correct nozzle dimensions can be determined we must know from experiments the probable steam friction loss in the nozzle and then the design of the nozzle is easily accomplished.

We shall not enter into the discussion of any of the other mentioned features of the steam turbine, but will say in conclusion that the development of the steam turbine within the last few years has been remarkable. It has already reached a position not only of equality with the best modern engines, but its high efficiency, its lower first cost, smaller size and cost of operation have placed it in the very foremost of steam engine practice. It is the belief of engineers now engaged in steam turbine designing that as soon as they have solved some of the important phenomena connected with steam flow that the turbine will entirely outrank the reciprocating engine.

In the steam turbine we are confronted with an entirely new series of phenomena. The knowledge of steam accumulated by familiarity with the reciprocating engine is of little use in designing this newest yet oldest of prime movers. Nor can the cut-and-dry methods that have brought the reciprocating engine to its present, and it may be said, its final stage of excellence, be employed in the steam turbine. Modern commercial conditions are such that design must be based on ascertaining physical laws.

This rapid advance has necessitated the re-investigation of steam from the point of view of velocity instead of pressure, of kinetic energy instead of potential, and the friction of rapidly moving bodies against a vapor instead of a lubricated surface, of the balancing of parts so that they shall revolve about their center of gravity, and of numerous other questions which are but beginning to make themselves felt.

The available data are few, and practically all of the information is scattered through the pages of German and French scientific periodicals and a few scientific books.

Mr. J. A. Lafore.—In the very interesting table presented by Professor Spangler, showing the relative economies of various engines and turbines, I would call attention to the fact that

the actual comparison between different types of apparatus in the matter of economy is clearly indicated by the horse power of any particular unit as compared with the horse power of the other units at the same position in the list. It is of course to be expected that the economy of an engine or turbine increases with an increase in size, and if the 300 H.P. unit of one type is of the same economy as a 1000 H.P. unit of another type, it is reasonable to suppose that the former represents the most economical type. I wish to call attention to the position of the De Laval apparatus in this list, particularly the 150 H.P. unit, which you will note stands side by side with other apparatus of many times its capacity.

I shall describe briefly the general construction of the De Laval Steam Turbine, but wish to speak particularly of the application of the turbine for driving apparatus other than electrical machinery.

The steam turbine is, of course, best adapted for furnishing power where the conditions require comparatively high speed, and where rotary motion is desired. These conditions are met with in electrical generators, and for this reason the greatest development in the application of the steam turbine has been in the driving of direct-connected electrical machinery. The high rotative speed does not detract from the efficiency of the generators, though, of course, in direct current apparatus the matter of satisfactory commutation must be considered, which makes it inadvisable to drive direct current machinery by certain types of high speed turbines, to which alternators can be attached satisfactorily. In comparing the advantages of the single wheel and multiple wheel turbines, this point should be considered, as a single wheel turbine with a reduction gearing readily permits of connection to direct current generators at practically standard speeds. Speeds sufficiently low are not readily secured with multiple wheel turbines, without impairing their efficiency.

In addition to driving electrical generators, the turbine is now used for many purposes, and will no doubt in the future be developed for many different classes of service. It is probable that we may look for great development in steam engineering along this line, and the De Laval Steam Turbine Co. has already a large number of turbines in operation direct con-

nected to pumps and blowers, and also driving line shafting by means of belts.

The impact turbine, devised by Branca, consisted of the vaned wheel, upon which steam issuing from an orifice impinged. This type of wheel, now generally known as the "De Laval," depends largely for its efficiency on the diverging nozzle of De Laval, which has been so ably discussed by Dr. Lœwenstein, and which is now used in one form or another in many types of turbine.

Figure 1 shows a standard De Laval nozzle set in turbine case with valve seated against the entrance to nozzle. The steam in case passes through the nozzle, impinging against the buckets as shown. If the nozzle is properly designed the steam leaves the exhaust end of the nozzle in a nearly parallel jet, moving in the direction of the axis of the nozzle at the point of exhaust, and has little tendency to move in any other direction. The steam is expanded in the nozzle between the working limits of pressure, the available potential energy between these limits being changed to kinetic energy, and the kinetic energy transferred to the turbine wheel. The steam issues from the nozzle at a very high velocity, 4500 feet per second being secured under favorable conditions in practice.

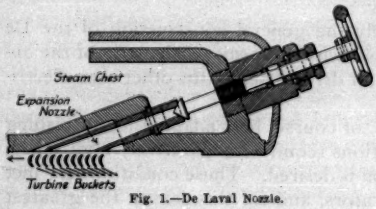

Fig. 1.—De Laval Nozzle.

While a velocity of over 4,000 feet per second can readily be secured from the exhaust of the diverging nozzle, the conversion of the kinetic energy in the steam to useful work presents engineering difficulties of considerable proportions. In order that all the work of the steam shall be given to the buckets on the moving wheel, it is obvious that the velocity of the steam on leaving the wheel must be nil. relative to the nozzle, and it is easily seen that this is the case when the speed of the wheel is one-half that of the steam, presuming that the steam impignes on the wheel in a direction at right angles to the face of the buckets, and in the plane of the wheel. As the nozzle is set at an

angle of about 20° to plane of wheel, the speed of wheel should be actually somewhat less than this. The high peripheral speed necessary to secure economical results necessitates great care in designing the turbine wheel. The De Laval wheel is of the kind shown in Figure 2. The wheel is a nickel steel forged

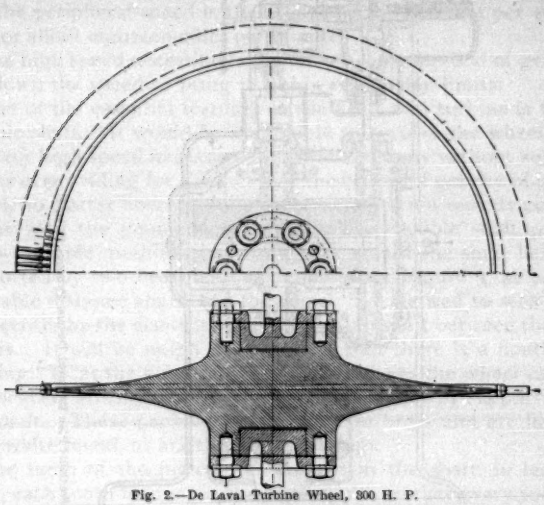

Fig. 2.—De Laval Turbine Wheel, 300 H. P.

disc, very thick at the center and tapering towards the edges. The factor of safety at normal speed is about 8. It is carefully balanced, and the rim contains a number of milled slots with holes drilled at their bases, in which the vanes or buckets are held. The buckets are made of drop forgings of steel with bulb shanks, and are fitted in the rim of the wheel by being driven in from the side. The outer wedge of the bucket is enlarged to rest against the next bucket, so that a complete set of buckets make a ring forming the outer circumference of the wheel. The massive hub of the wheel is constructed solid in all of the larger sizes, and the shaft is built in two pieces, and bolted by a flanged connection to the wheel. In the smaller machines the shaft passes through the hole in the center of the wheel.

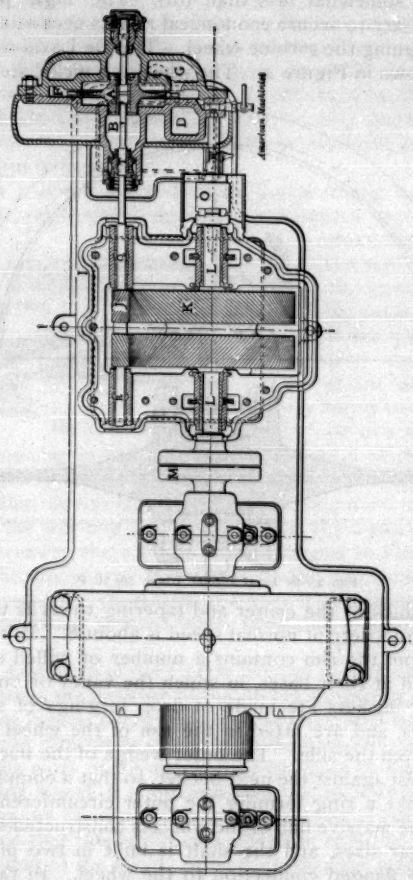

Fig. 3.—Sectional Plan De Laval Turbine Dynamo, 20 H. P.

The wheel revolves free, in a cast-steel case, there being a clearance of about $\frac{1}{8}$" to $\frac{1}{4}$" between the nozzles and the buckets.

A 300 H.P. wheel is about 30" in diameter between centers of blades, runs at approximately 10,600 revolutions per minute, and the peripheral speed is therefore about 1,600 feet per second, or about eighteen miles per minute.

The high speed necessitates the use of some method of gearing down the speed to bring it within reasonable limits.

One of the essential features of the De Laval turbine is the flexible shaft. It would be impossible to revolve the wheel at the very high speed necessary for good economy without some means of providing for the fact that the center of gravity of any wheel, no matter how carefully constructed, is not exactly coincident with the geometrical center. The flexible shaft provides a simple method of securing this result, the shaft being supported by two bearings, "Q" and "S" in Figure 3, at considerable distance apart, and the wheel "A" allowed to seek its own center by the elasticity of the very thin shaft between these points. It will be noted from the cut that there is a floating bearing "T" at the point where the shaft leaves the wheel case, this bearing serving as a packing box and in no way supporting the shaft. These packing bearings are of brass and are lined with white metal, as are the other bearings.

The teeth of the pinion "J" are cut in the shaft, in large sizes, each tooth forming a complete spiral, so that every tooth is in service all the time. The gear wheels, "K," are of cast-steel faced with a steel forged band, in which the teeth are accurately cut. It will be noted that the pitch of the teeth is exceedingly small, being in the three-hundred-horse-power size only about one-quarter of an inch. In the larger turbines the pinion and gear wheels are in the ratio of approximately one to twelve, and in the smaller turbines in the ratio of one to ten. The peripheral velocity of the gear wheel is about 6000 feet per minute. On turbines of seventy-five horse power and above, a double gear is used, this decreasing the side thrust on the high speed shaft. These gears will operate for many years without wearing, the European De Laval Companies having had them in service as long as eight or nine years, and no gear wheels have, up to the present time, any marked deterioration.

All bearings consist of brass sleeves lined with babbitt metal set in ground boxes in the turbine frame without any means of adjustment. Any bearing on the turbine can be removed and a new one substituted without removing the shaft.

The governor is of the centrifugal type, consisting of a split cylinder operating on two knife edges, the action of the centrifugal force being resisted by a double spring. The moving parts are light and the friction exceedingly small, which results in very quick action. The governor valve is a double-balanced poppet valve. There is also provided in condensing turbines a valve in the wheel case, upon which the governor acts when the turbine, due to suddenly throwing off a heavy load, tends to race, this valve breaking the vacuum and reducing at once the speed of the wheel. I believe that better regulation is secured by a combination of this governor and the vacuum valve than is possible with any other type of condensing turbine or compound engine.

The centrifugal pump, which offers many advantages not found in other types of pumps, requires a higher peripheral velocity of runner for satisfactory operation, and is therefore particularly well suited for direct connection to steam turbines. The De Laval Steam Turbine Company manufactures the pump and steam turbine complete as one unit. The standard pumping unit consists of the turbine with geared down shafts, which drive the pump runners, but the Company has developed a rather remarkable pump for high pressure service. This pump is compound, two runners being used in series, one being coupled direct to the high speed turbine shaft and the other to a shaft geared down and operating at a lower speed. The low speed runner, which operates in a separate case, entirely independent of the high speed part, does only about 20% of the work, serving merely to deliver the water to the high speed pump. The high speed runner, which is remarkable because of the speed at which it operates and its size, receives the water from the other runner and delivers it under heads as high as 700 feet. The high speed runner, however, will not lift water, and it is therefore necessary to use the low speed runner to secure the necessary suction, unless water is delivered to the pump under some head.

Figure 4 shows, full size, a 60 H.P. high speed runner, which

handles 250 gallons of water per minute against 700 feet head and operates at a speed of 20,000 R.P.M.

The economy of space in the installation of a pumping unit is frequently of considerable importance, and in the feature of small space occupied, the steam turbine pump stands entirely alone. Figure 5 shows a standard pumping engine, made by one of the largest manufacturing companies in the country, having a normal capacity of 1800 gallons of water per minute

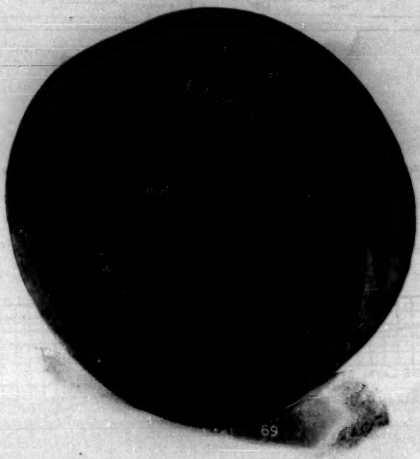

Fig. 4.—Full Size De Laval High Speed Pump Runner. 250 Gallons Per Minute. 700 Ft. Head. Speed, 20,000 R.P.M

against a pressure of fifty pounds, and a De Laval Steam Turbine pump of the same capacity. The illustration shows only the difference in floor space required,—the difference in size of foundation is equally marked.

It may be of interest to the members to note a test of the centrifugal pump and steam turbine when operating under ordinary conditions, with a comparatively low vacuum, as shown by the test of Messrs. Denton & Kent. The curves (Fig. 6)

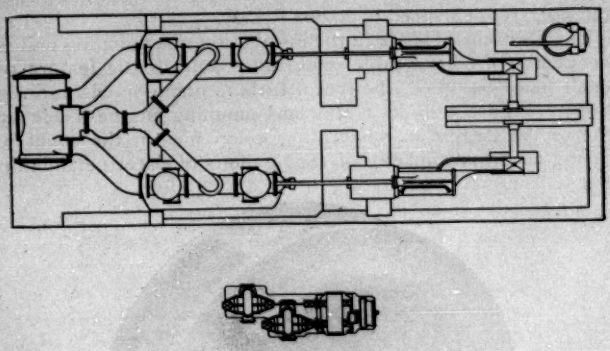

Fig. 5.—A Corliss Pumping Engine and a De Laval Steam Turbine Pump of the same Capacity, both Drawn to the Same Scale.

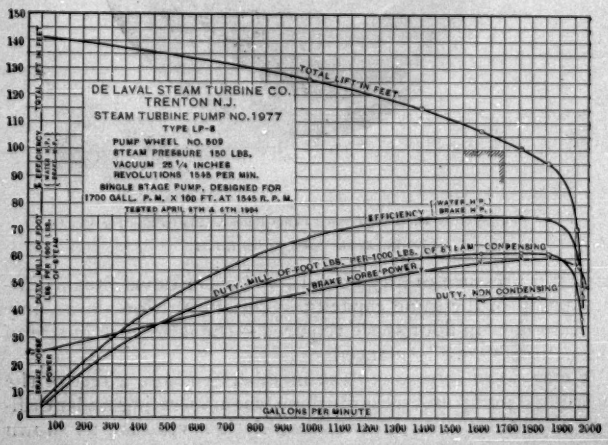
DE LAVAL STEAM TURBINE CO.
TRENTON N.J.
STEAM TURBINE PUMP NO. 1977
TYPE LP-8
PUMP WHEEL NO. 809
STEAM PRESSURE 150 LBS.
VACUUM 25¼ INCHES
REVOLUTIONS 1545 PER MIN.
SINGLE STAGE PUMP, DESIGNED FOR
1700 GALL. P. M. X 100 FT. AT 1545 R. P. M.
TESTED APRIL 5TH & 6TH 1904
TOTAL LIFT IN FEET
EFFICIENCY
DUTY, MILL. OF FOOT LBS. PER 1000 LBS. OF STEAM CONDENSING
BRAKE HORSE POWER
DUTY, NON CONDENSING
GALLONS PER MINUTE

Fig 6.—Characteristic 55 H. P. Turbine Pump. Steam Pressure 180 Lbs. Vacuum 25¼ Inches.

show clearly the results of this test. It should be noted that this is a comparatively small unit, being only of 55 H.P. capacity. It is shown in Figure 7.

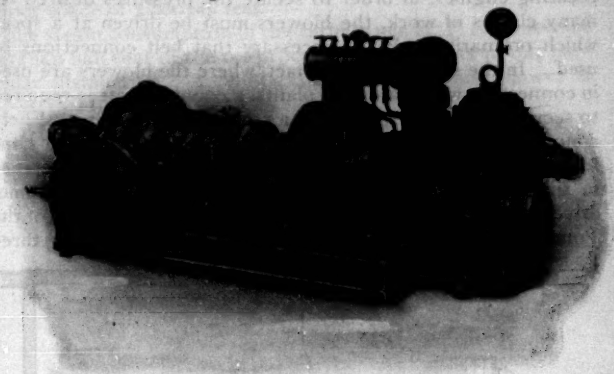

Fig. 7.—De Laval Steam Turbine Centrifugal Pump. 1700 Gallons per Minute. 100 Ft. Head.

Figure 8 shows the general construction of pump furnished for direct connection to turbine. The bearings are ring oiling. There is a drip chamber between packing box and bearing and

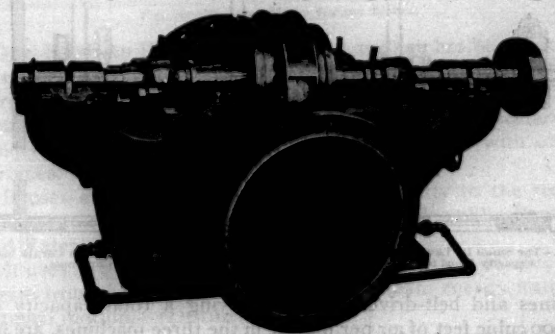

Fig. 8.—De Laval Centrifugal Pump with Upper Portion of Case Removed.

the upper half of case is removable. Runner is made of bronze.

One of the most suitable applications of the steam turbine is

for driving blowers and exhausters, and the De Laval Company are now building many turbines for this purpose. With reciprocating engines, in order to secure the pressures desired for many classes of work, the blowers must be driven at a speed which ordinarily makes it necessary that belt connections be used. In the smaller sizes, in fact, where the blowers are used in connection with water gas plants, a counter shaft is required to secure the proper speed with a reciprocating engine. Where connected to a turbine, they are mounted directly on the same base, and form a very compact unit. To indicate the difference in size between the old form of apparatus and the turbine-driven blower, I have shown to scale in Figure 9 a portion of the Point Breeze plant of the Philadelphia Gas Co., where three

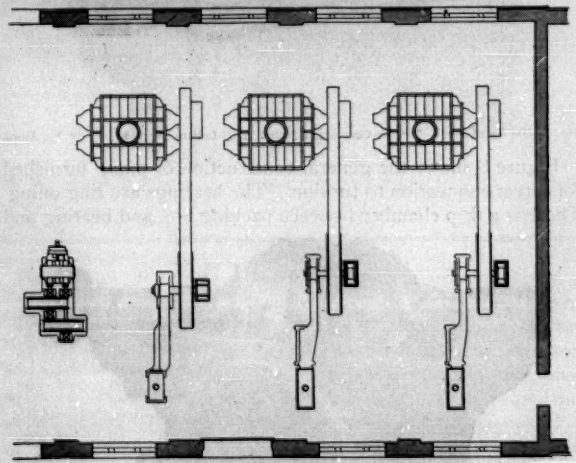

Fig. 9.—The Small De Laval Steam Turbine Blower Shown in the Lower Left-hand Corner has a Capacity Equal to one-half that of the three Engine-driven Blowers Combined.

engines and belt-driven blowers, having a total capacity of 60,000 cubic feet of air per minute in the three machines, are installed. The small De Laval outfit to the left has been recently placed to increase the capacity of this plant. This steam turbine blower is about half the capacity of the other three units

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combined. In other words, with two De Laval turbines occupying a floor space of 300 sq. feet, the same result would be secured as with the three belted blowers and engines occupying a floor space of 3,000 sq. feet.

The steam consumption of the turbine per H. P. is somewhat less than half that of the reciprocating engine units in this particular installation. A photograph of this turbine blower is shown in Figure 10.

Fig. 10.—De Laval Steam Turbine Blower.

MR. RICHARD H. RICE.—The Curtis turbine has been extensively described in the technical press and in papers read before various Engineering Societies, therefore no extended description need be given here. I will only give enough particulars to render its distinctive features clear in comparison with other turbines.

It uses expanding nozzles to impart velocity to the steam before entering the buckets. (Like De Laval; unlike Parsons and Rateau.)

It uses two or more rows of revolving buckets to receive the steam from the nozzles and convert the steam energy into rotational motion. (Distinctive.)

It has several stages, each one consisting of nozzles, combined with two or more rows of moving buckets and their corresponding stationary buckets. (Distinctive.)

It has a very moderate number of stages, two to six. (De Laval, 1; Zoelley, 10; Rateau, 25; Parsons, 40 to 50.)

It is governed by discharging steam at full pressure through the proper number of nozzles to suit load requirements without throttling. (Distinctive. Others throttle, except Parsons, who governs by varying the amount of periodic puffs.)

It employs wheels of considerable diameter, occupying short lengths of shaft, with moderate bucket speeds. (De Laval and Zoelley, high buckets speeds, Zoelley, Parsons and Rateau long shafts.)

It uses only a small arc of admission to the first stage. This admission arc is divided in the larger machines into two parts. The active nozzle forms a continuous belt discharging steam in such a way as to produce an uninterrupted band of steam entering the buckets and this band is varied in width by the governor in accordance with load requirements. (All others but De Laval use the entire circumference, and De Laval uses isolated single nozzles.)

All sizes developing any considerable power have vertical shafts. (Distinctive.)

Briefly stated, the vertical form of Curtis turbine, which include all sizes of 500 K.W. capacity and upwards, consists of a turbine with a vertical axis having two or more stages and taking steam at pressure from 100 to 200 lbs. per sq. inch, and exhausting either into the atmosphere or into a condenser. Above the turbine is mounted an electric generator directly on the same shaft. The shaft is supported by and rotates upon a frictionless fluid step bearing. The governing is done by means of individual valves, each controlling one or more nozzles, these valves being mounted on the top head of the turbine and actuated by a suitable mechanism which is influenced by a governor placed on the top end of the shaft, which governor regulates the speed by opening one or more valves as the requirements of the load may dictate.

The sizes below the 500 K.W. capacity are of the horizontal form and of various designs, to suit the special requirements of the services for which these turbines are intended. Those up to 75 K.W. capacity are of the overhung type, consisting of one or more wheels keyed to the end of the shaft and surrounded by a suitable casing. These over-hung shaft turbines

have throttling piston valves directly controlled by a governor on the end of the main shaft. From 75 K.W. to 300 K.W. capacity the turbine has four bearings, with separate turbine and generator shafts connected by a flexible coupling. These four-bearing sets have governors of the same type as those used on the vertical machines.

Referring to the literature above quoted for further particulars and description of mechanical details, I will call your attention to various applications of Curtis turbines which have already been made.

The turbine, by virtue of its high speed, lends itself readily to connection to electric generators, and only one of the various types now on the market requires gearing to reduce the speed of its shaft to a suitable figure for connection to the generator. All others have the generator mounted on the turbine shaft or a continuation of it, and move at the same speed.

There are, however, considerable differences in speed of the various types, and among them the Curtis speeds are the lowest. This fact permits the generator end, as well as the turbine end, to be very conservatively designed, and as a matter of fact the generators used with the Curtis turbines are among the best ever constructed by the General Electric Company. This has an important influence on the results obtained by the operation of these units, since highly efficient generators mean that more of the energy contained in the steam is delivered at the switchboard in the form of electrical power. The generators have very conservative constants and a considerable overload capacity, which characteristics fit them for action with all varieties of load and for all purpose demanding flexibility, good regulation and steadiness of operation; and combined with the small internal friction of the vertical type, ensures the maximum conversion of energy in the steam into useful work.

These turbines, having so moderate a speed, are peculiarly adapted to direct connection to turbine and centrifugal pumps, air compressors and other high speed machines, and considerable progress has been made in such directions, which, however, will be the subject of description elsewhere and at a future time.

Ordinarily, since the turbine derives great benefit from the production of a good vacuum at its exhaust outlet and is able to

utilize such a vacuum to a greater extent than any other heat engine, and since it can deal with high pressures in the inlet, it is assumed that such conditions are necessary to its proper performance.

The fact is, however, that the turbine can be economically operated as a non-condensing engine, and many turbines of the Curtis type have been built and are operating non-condensing with satisfactory results. In economy it compares with the older type of engine with which it is in competition, while the almost automatic operation of the turbine, its small floor space, its quiet operation and the absence of oil in the steam all make it a desirable substitute.

Another promising field for the turbine, which has been pointed out by Mr. W. L. R. Emmet, is in utilizing the exhaust from reciprocating engines, operating either condensing or non-condensing. To provide further power, the turbine exhaust is turned into a condenser, furnishing a high vacuum. The Curtis turbine is very responsive to the influence of a high vacuum and gains rapidly in efficiency as the excellence of the vacuum increases. It is therefore very appropriately used in this way, and in connection with engines discharging steam and atmospheric pressure the turbine will more than double the useful effect of the steam. For instance, when used in connection with an engine exhausting at 24″ vacuum, about 20% additional power will be realized.

It will be seen that the turbine in this way opens up a most promising field for the improvement of existing plants, enabling the output to be largely increased with a small capital outlay and reducing thereby the operating costs.

Various special applications have been made from time to time of Curtis turbines, owing to the peculiar adaptability of the turbine set for use in locations where weight and the cubic space occupied cut an important figure with turbine sets of small size. I will only instance one or two applications.

Many sets are in use for generating the current used in lighting trains. In these cases the turbine set has been installed on the buffer beam of the locomotive, on top of the boiler or in the baggage car. In the first two cases the steam pressure used is that of the boiler, say 175 to 200 lbs., and in the case of sets in the baggage cars the pressure is the same as that

in the steam piping conveying steam through the train for heating, say 50 to 80 lbs. In either case, the sets are used in conjunction with storage cells, which furnish current when the train is in the station and the locomotive is being changed.

Some work has been done in developing headlight sets, using for this purpose turbine sets of 1¼ K.W. capacity. This set is mounted with the headlight on the usual bracket immediately in front of the smokestack.

These applications will be enough to indicate the great flexibility and adaptability of the turbine for use in severe and unusual locations.

Since the steam which has been passed through the turbine is entirely free from lubricating oil, this fact directed attention at the outset to the advisability of condensing this steam in surface condensers, in order that pure feed water might be secured for the boiler and the water consumption, especially in cases where feed water is impure or expensive, might be kept as low as possible, using as cooling water any inferior source of water supply which would in general cases be unsatisfactory for boiler purposes. For instance, in cities on the seaboard, the supply of fresh city water could be reduced to a minimum and the circulating water could be salt.

Due to these considerations all the first Curtis turbines were fitted with surface condensers.

Since the turbine utilizes the expansion of the steam completely while the reciprocating engine does not, for reasons well known, it was found early in the developmental period that it would pay to put in large condensers and obtain much better vacua than usual. The condensers do not, however, need to be very much larger, since turbines are free from air leakage, which it is almost impossible to prevent in engines having a considerable number of piston and valve rod stuffing boxes, and also because, oil being absent, the cooling surface retains its efficiency indefinitely.

The use of dry air pumps, already in vogue by condensing engineers in cases where the best results were desired, has been quite generally extended to turbine condensers, and in case the temperature of the cooling water is not too high, vacua of 28″ and 29″ are readily produced, while the power required to

drive the pumps for this purpose varies from 2½% to 4%, depending upon the design of the circulating water passages.

Other types of condensers are gradually coming into use on our turbines, in cases where an abundant supply of good water is obtainable, one of which types is the jet condenser, running with injection and dry air pump. If the proper allowances are made in proportioning the dry air pump for the dissolved and entrained air in the water, and if the water is permitted to settle and discharge the entrained air before being pumped into the system there will be no difficulty in obtaining good results.

The same remarks apply to siphon condensers, and there will be, with proper proportioning, no difficulty in obtaining first-class vacua with this type.

In cases where water is scarce, a cooling tower may be used. I have obtained guarantees of 27″ with these, used in connection with turbines for summer temperatures in Northern states, and with condensing outfits proportioned to meet these guarantees expect to realize 28″ during at least five months of the year. Experience will soon be available on at least one of such installations.

The Curtis turbine, on account of the originality of its construction, has naturally exercised an important influence on power house design. This influence has been exerted in the directions of treatment of accessories, arrangements of boilers, and floor space.

With the adoption of vertical shaft turbines, which only require a low circular foundation, four to six feet in height, the practices existing in a reciprocating engine station, as to fixing of floor levels and provision of basements, no longer obtained. It was recognized that the basement and engine room floor could, in many cases, be advantageously combined. This arrangement at last gives the accessories of the turbine their proper place as an integral and necessary part of the apparatus of the station, and also necessitates (what needed to have been done before) the placing of this apparatus on the principal floor level, with good light and perfect accessibility, so that proper care and attention must of necessity be given.

Because of the small floor space occupied by the turbine per unit of power, the usual arrangement of the boilers in single or double lines parallel with the engine room, was found to leave

too much unoccupied space in the latter. Arrangements therefore naturally came into vogue whereby the boiler room space is more advantageously disposed, either in the form of a double-decked boiler room, in particularly crowded locations, or in the arrangement of boilers in rows perpendicular with the axis of the engine house, so that each perpendicular row of boilers would have sufficient capacity to supply one turbine. This latter arrangement is that most generally useful, and splendid stations built on this plan may be seen at Chicago and Boston.

Recently, in some stations, accessories, such as pumps, condensers, heaters, etc., have been placed in another room apart from the turbine, so that some stations are now divided into three rooms, the boiler room, the turbine room and the condenser room.

In lighting stations, moreover, the switchboard has become extensive and important and questions of safety and convenience dictate the placing of all these parts in a separate house.

Modern station design with turbines has therefore proceeded along lines of specialization and the confinement of zones of trouble within very narrow limits, the apparatus outside of which is extremely unlikely to be simultaneously affected.

Mr. John H. Macalpine then made the following remarks on the "Relative Economy of Reciprocating Engines and Turbines for the Propulsion of Ships."

Founding on the data available up to the time of printing the Report, which Admiral Melville and I made to Mr. George Westinghouse, on Steam Turbines, especially with regard to their application to the propulsion of ships, we stated:—

1st. We are inclined to believe with Professor Rateau that the lower limit of speed (of ship) for the effective use of the turbine is not under twenty knots, and we think it may possibly be higher.

2. That the consumption in small warships at half speed is nearly twice as great with the turbine as with the reciprocating engine.

3d. No allowable addition of cruising turbine can come

near making the pressure gradients as small as would be required to maintain full power economy at half speed.

These conclusions seem to be confirmed by the most recently published data obtained by the British Admiralty trials of H.M.S. Amethyst, taken in conjunction with the trials of H.M.S. Usk, the data for which were given to us by the British Admiralty. The trials of H.M.S Amethyst and Topaze are published in *Engineering* of November 18th, 1904.

The results of the Amethyst are better than those from the previous turbine ship, H.M.S. Eden; partly, we understand, from a general improvement in the design, and at low powers from the introduction of two cruising turbines through which steam has to pass in succession before reaching the H.P. and two L.P. turbines; the H.P. and L.P. turbines being used alone at full speed. But still this large addition of cruising turbine has, as we anticipated, not brought down the low speed results to nearly the economy attainable with the reciprocating engine.

No doubt these trials of the Amethyst and Usk are strictly comparable, as they were all carried out by the Admiralty experts, and in all cases only the necessary number of auxiliaries would be kept in service.

The trials of the Usk gave for the coal per indicated horse-power per hour,—

At full speed, 25,372 knots.....1.79 pounds
At half speed, 13.0 " .....1.30 pounds

The accompanying diagram is a reproduction of Fig. 4, from the above copy of *Engineering*, page 691, to which we have added a curve U for the Usk. The rates for the Usk's evaporation per pound of coal, which data was not given to us by the Admiralty, are founded on the figures given in *Engineering*, Nov. 18th, for the Amethyst, Topaze and Sapphire.

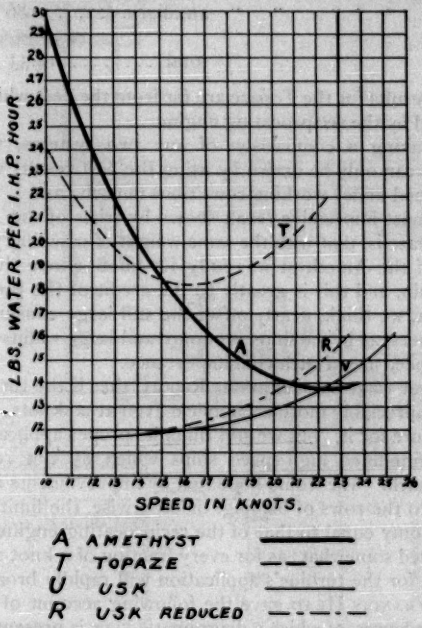
At full power.....8 pounds
At 30 knots.....9 pounds

This gives for the Usk,—

At 13.0 knots, 1.30x9=11.7 lbs. water per I.H.P. per hour.
At full power 1.79x8=14.32 lbs. of water per I.H.P. per hour.

Curve U connects the above two values, and was made concave upwards, which is no doubt correct; its exact form we

have no data to determine. I have been informed that the low power test of the Usk was with one engine only, but I cannot state this positively. This, of course, is perfectly legitimate. The curve R is the Usk's curve U drawn to a smaller scale of knots, so as to make her full speed the same as the full speed of the Amethyst, 23.63 knots, and thus make a comparison truer,



A AMETHYST
T TOPAZE
U USK
R USK REDUCED

especially regarding the speed for equal economy shown by the point at which the curves A and R intersect. The intersection occurs between 20 and 21 knots.

The Usk was the most economical of any of the ships for which data was given us by the Admiralty; but, especially at low powers, it is by no means so good as can be obtained with the reciprocating engine. In the Saxonia at what must have

been practically full power, as the mean pressures attained show that the H.P. cut off was about .7, the Boiler Committee of the British Admiralty found the following results: (See *Engineering*, Vol. 73, page 278.)

Coal	per	I.H.P.	per	hour	.....	1.29 pounds
Water	"	"	"	"	main engines...	13.47 pounds
"	"	"	"	"	auxiliaries.....	0.86 pounds
"	"	"	"	"	total.....	14.33 pounds

The results for the Topaze are far from the best which can be obtained by the reciprocating engine.

In making a comparison of any two systems, true conclusions can only be drawn by using the best results which can be attained under working conditions in each case.

The most impressive result shown by trials of the Amethyst and Topaze is, that with the same weight of machinery, the full speed of the Amethyst was fully 1.5 knots above that of her sister ship, and this is greatly to the credit of the turbine. It does not, we think, nearly offset the still large consumption at low powers, as in warships economy and large radius of action at low speed are of such vital importance.

I repeat what we said in our Report, that if the turbine "did prove appreciably more economical even at 20 knots, there is a wide future for it," but we still think its proper application only lies in fine-lined high-speed ships which do not require to cruise much. We would hope that by improvements in design, adding to the rows of blading, or otherwise, the limit of speed for economy equal to that of the reciprocating engine will still be lowered somewhat; as for every fraction of a knot so gained the field for the turbine's application will rapidly broaden.

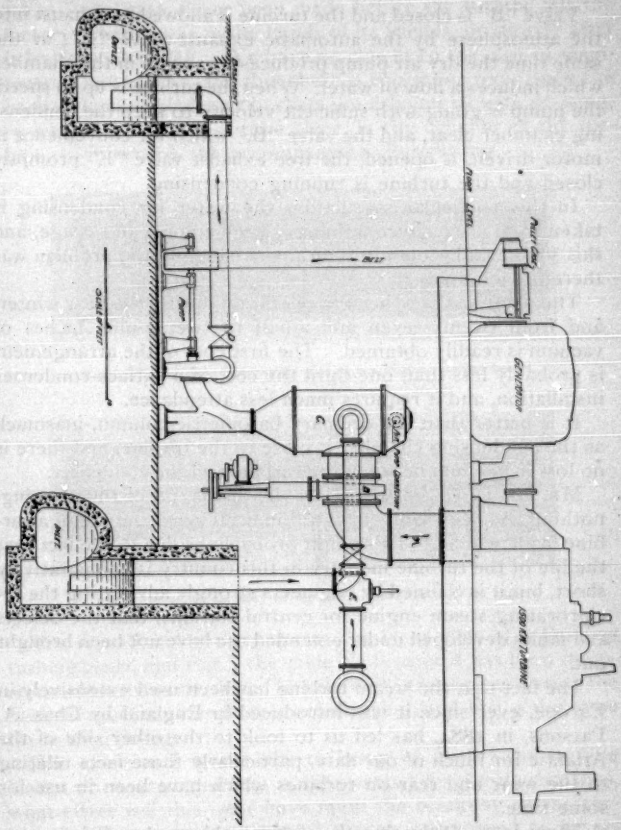
MR. FRANCIS HEAD gave the following account of the Turbine Condenser, of which a diagramatic view is presented:

The machine in question in a 1500 K.W. turbine of the Parsons type, which was built specially with an extended shaft at the generator end on which a pulley was placed.

The novelty of the scheme is in substituting a centrifugal pump for the usual barometric column.

The exhaust steam is lead through a pipe "A" and a gate valve "B" into the condensing chamber "C"; there, it is

condensed by a jet and flows into the opening of a centrifugal pump, which is driven by a belt from the pulley on the extended shaft of the turbine.



The Turbine Condenser.

There is a check "D" in the discharge from the pump, and this discharge is also sealed by the outgoing water. At the

top of the condensing chamber is attached the usual dry air pump connection.

The turbine is started as follows:

Valve "B" is closed and the turbine is allowed to exhaust into the atmosphere by the automatic exhaust valve "E"; at the same time the dry air pump produces a vacuum in the chamber which induces a flow of water. When the turbine is up to speed, the pump is going with sufficient velocity to keep the condensing chamber clear, and the valve "B," which for convenience is motor driven, is opened, the free exhaust valve "E" promptly closed and the turbine is running condensing.

In this particular installation the water for condensing is taken from a stream containing a large amount of sewage, and this simple and economical means of handling the problem was therefore adopted.

The plant has only been in operation during the past winter, and from twenty-seven and a-half to twenty-nine inches of vacuum is readily obtained. The first cost of the arrangement is probably less than one-third the cost of a surface-condenser installation, and it requires much less attendance.

It is better than the ordinary barometric column, inasmuch as the condensing chamber is close to the turbine, and there is no loss in vacuum between the turbine and the condenser.

Mr. Oscar C. Schmidt.—In the discussion of this evening, nothing has been said which will indicate what the life of a turbine blade will be. This might probably be due to the fact that the life of the turbine industry in this country is comparatively short, but it is claimed by engineers strongly advocating the reciprocating steam engine for central stations, that the defects and faults developed under extended use have not been brought out.

The fact that the steam turbine has been used extensively in Europe, ever since it was introduced in England by Chas. A. Parsons, in 1884, has led us to look to the other side of the Atlantic for much of our data, particularly those facts relating to the wear and tear on turbines which have been in use for some time.

There is no doubt that the steam turbine, when it is new, is an efficient and economical machine, so far as steam consumption is concerned, but what effect has long life upon this econ-

omy and efficiency? Nothing up to the present time has been published on this subject. All the tests which have been made in this country or Europe, and which have been published so extensively, have either been made before the turbine left the factory, when it was in the hands of its friends, or shortly after it had been installed. We have no clue as to the cost of maintenance and repairs, and that there is enormous wear upon the back of turbine blades or buckets, on account of wire drawing, or whatever really does take place, in the cylinder of the turbine, is shown by the accompanying illustrations.

Fig. 1.—Enlarged view of concave side of new Parsons turbine bucket.

Fig. 2.—Same bucket after having been in use less than one year.

The first illustration represents the front view of a Parsons turbine blade, and Fig. 2 the same blade after it has been in operation less than one year. The third illustration represents the back view of the same bucket before using, and Fig. 4 the same blade after using.

The question I would like to bring up is, "If the turbine blades do wear as much as is represented by the illustrations, what effect will this wear have upon the economy of the turbine?" The wear upon turbine blades is supposed to be reduced by superheating the steam and hence the getting rid of any entrained moisture or condensation is supposed to reduce

this wear to a minimum, but this turbine blade was taken from a 300 K.W. turbine which ran with superheated steam at a temperature of about 548° F., the initial steam pressure being 134 pounds per square inch.

As this blade is only one of 31,073 blades which are used in a Parsons turbine of 300 K.W. capacity, and if all the blades are worn after a few years of service to anything like those which are shown, the cost of repairs must necessarily be considerable,

Fig. 3.—Convex side of same bucket when new.

and what about the economy in the meantime? Of these 31,073 blades, 16,095 are moving blades and the difference, or 15,978, are stationary or guide vanes.

V.1
190

While it has been calculated that there is only a pressure of about one ounce which comes upon each blade as it is revolving, it might be probable that if only a few of these buckets were in the condition shown, the effect upon the economy might not be appreciable.

Fig. 4.—Same blade showing wear on convex side.

The fifth illustration represents a De Laval nickel steel bucket, which was in use less than six months, and it is evident that the wear upon one side of the blade was considerable. This blade was taken from a 30 K.W. De Laval turbine, in which there are about 200 buckets.

Fig. 7 represents a De Laval steam turbine cast-steel helical pinion, which was in use less than six months, and Fig. 6 represents a new pinion of the same size and type. The profiles

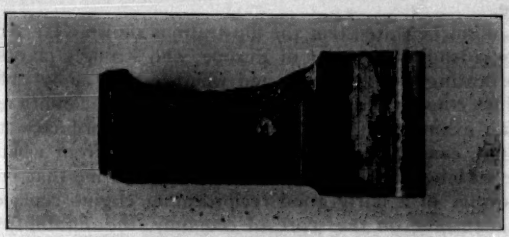


Fig. 5.—Enlarged view of De Laval turbine bucket in use less than six months.

of the teeth in the used pinion are considerably worn away by wear. With the case of the pinion, the cost would be so low that even it it had to be replaced a number of times in a short

Fig. 6.—De Laval cast-steel pinion.

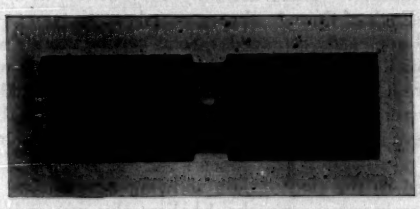


Fig. 7.—Same pinion after having been in use six months.

time, it could hardly be held of great importance against the De Laval turbine.

The question of wear upon the turbine blades of any turbine cannot be so easily dismissed, as the cost of replacing the blades of any of the high power turbines would be quite a serious expense.

It might be stated that the illustrations shown were sent to me by a leading engineer of Europe, who strongly favors the reciprocating steam engine, and whether they apply only to turbines constructed and operated under worst conditions, or are fair examples of the wear and tear on the ordinary steam turbines, cannot be stated, but it seems that from whatever cause turbine blades do wear, and it seems to me that before any owner of a fairly good reciprocating engine replaces it with a turbine on the score of economy, the durability and economy of the turbine after years of service should be fully known.

MR. LAFORE.—In regard to the wear on the De Laval bucket as shown by the view, I believe that such a statement is of little value unaccompanied by exact information as to where the machine was used and some definite information which will establish without question the fact that the bucket was subjected only to normal wear. It has been clearly shown both in practice and by experiments, made by Prof. Spangler and many others, that a steel bucket will not wear materially if subjected to a jet of dry steam. It is, of course, easy to show a worn part of any machine, but I think little importance should be attached to any individual exhibit of this character. As a matter of fact there are not 200 buckets in a 30 H.P. turbine, but only about half this number. There are only 200 buckets in a 300 H.P. turbine. Each of these buckets costs about sixteen to eighteen cents, and are easily replaced. So it can be readily seen that even if a bucket did wear, the expense of replacing it would not be very great. Further, I would state that some buckets with the edges purposely cut away have been tested in turbines and the decrease in economy is very slight, only a few per cent. in fact.

In regard to the photograph showing new pinion, and one having been in use six months, I believe this may indicate little more than a difference in the character of the photographs, and that the same results might have been secured if two photographs had been taken of the same pinion at the same time.

Without regard to this, however, it is self-evident that such exhibits are of little value without absolute knowledge that the pinion was not improperly treated, or subjected to unusual wear. Gears and pinions have been in use in Europe and in the United States for a number of years and have shown no perceptible deterioration, excepting where an accident occurred or some foreign material was allowed to enter the gear case.

Notes and Comments.

THE PANAMA CANAL.

Although it is usually a good proposition to get the best, the principle may not apply with regard to the d'gging of the Panama Canal. Chief Engineer Wallace strongly favors its construction at sea level, and advances cogent arguments in support of his opinion. He has advised the House Committee on Interstate and Foreign Commerce that a canal so constructed would be less expensive to maintain, less expensive to operate, would save time in passing through it, and could be widened and deepened when required without interfering with traffic. All these are very good reasons, indeed, why a sea level canal should be dug rather than one with a portion of its channel 90 feet higher, requiring the use of locks. But, unfortunately, there are other considerations. Taking as a basis the estimate of the former Canal Committee, that the 90-foot level canal would require ten years for its completion and would cost $200,000,000, he figures that a sea level canal could be opened in fifteen years and completed in twenty years, and would cost $300,000,000. The increased cost will propably not strike the American people as a formidable objection to the adoption of a level which will have so many advantages over one requiring locks, although an extra $100,000,000 is no trifling matter to be lightly considered. The most serious point brought out is the greatly extended time required.

Mr. Wallace bases his estimate on a previous estimate, and both may be much out of the way. Difficulties greater than have thus far been conjectured may develop as the work proceeds, and its completion even at a 90-foot level might be delayed considerably beyond ten years. The attempt to dig a sea level canal might be prolonged far beyond fifteen years until the canal could be opened to vessels of light draft, and it might be twenty-five years until the largest vessels could safely venture through. Those who have been most earnest in their support of the Panama Canal have, of course, been animated either by hopes of a personal benefit or of benefit to existing commercial interests. Surely those who have labored for it in season and out of season were fairly hopeful that if undertaken it would be completed while they were sufficiently interested in mundane affairs to take some cognizance of the fact. But to defer such a hope for twenty or perhaps twenty-five years would mean that very many who are now deeply interested are merely working for the benefit of posterity. If a sea-level canal should be decided upon, it is to be hoped that the estimates of both cost and time are far out of the way, and that both can be heavily reduced. Most especially is it desired that the time can be shortened.—*Iron Age.*

NEW PROCESS OF COLOR PHOTOGRAPHY.

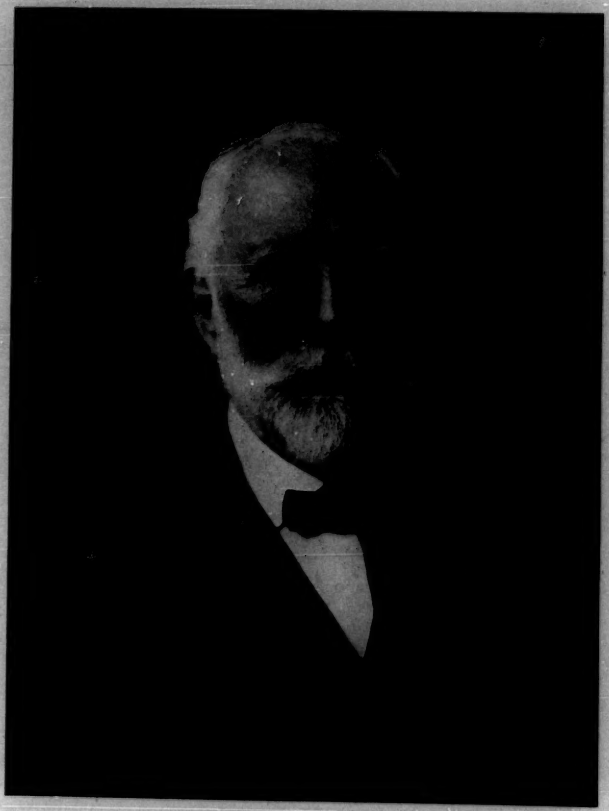
Scientists, dabblers in science and earnest amateur photographers have been trying for years to discover the secret of producing photographic prints in the colors of nature as seen upon the ground glass of the camera and as projected by the lens upon the sensitized plate. The lens views and the plate receives the picture in colors, but the negative plate is incapable of fixing anything else than form and producing that in fine gradations of light and opacity. Color negatives have been made, but have not been capable of transmitting color qualities to positives, nor have color positives been successfully made by any purely photographic principles. Good color effects are produced by superimposing photographic plates in mechanical printing processes, but hitherto there has been little success in chemical reaction upon ordinary printing paper to produce color effects.

Recently, Rudolph Isenmann, of 385 Bergen Street, Newark, N. J., has produced some most promising effects in making color photographs by purely chemical manipulation in the simplest possible manner. With ordinary printing-out paper, either gelatin, albumen or collodion surfaced, such as is sold by photographic stock houses, he claims to make prints containing blue, yellow, green and brown by merely soaking the prints as taken from the printing frames in two successive baths with a washing between the chemical immersions. The colors find their places with wonderful accuracy. The rich cerulean blue arranges itself in the sky with white cloud effect, and in the sunlit parts of the water in the foreground, while the water in the shade of the green trees takes up a greenish cast and the browns and autumnal yellows appear on the leaves and are reflected in the water in some of the pictures. The arrangement of the colors seems to be natural selection influenced entirely by the density of parts in the negatives from which the prints are made. Mr. Isenmann says that he allows the colors to work out their own progress, and never uses any effort to direct them by hand manipulation. He says, further, that the process is extremely simple and cheap. He uses no gold in toning the pictures, nor does he use hyposulphite of soda to fix them. What becomes of the free silver he does not say, but he has samples of his color work which have been made and exposed for six months, and he can see no change in the colors.

While Mr. Isenmann's results are by no means perfect, they show great advance in color photography, and give promise of still greater success. He despairs of ever reaching the reds by this process, but feels that he has secured a satisfactory end by extremely simple means.—*Scientific American Supplement.*

IRON AND IRON SUPPLIES.

Pennsylvania, which makes more than half the iron used in the United States, produces less than 2 per cent. of the iron ore mined. Ohio, which comes next to Pennsylvania as an iron-maker, mines less than 0.1 per cent. of the total. In both cases the ore is brought to the fuel; and this is the policy in this country. Only in Alabama are the ore and fuel found together.



WILLIAM SELLERS,
1824-1905.
President Franklin Institute, 1864-1867.

OBERLIN
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THE FRANKLIN INSTITUTE

William Sellers.

When a man of pre-eminent abilities and world-wide fame as an engineer and manufacturer, whose life was spent in activities contributing to the advancement of knowledge in his chosen profession, passes away at a ripe old age—having retained to the last an active interest in his business and in public affairs—it is proper that a permanent record of his useful life should be made available for the benefit, not merely of his friends and contemporaries, but of future generations as well.

Such a man in all respects was William Sellers, the former President of the Franklin Institute, to whose solicitude was due, in large measure, the preservation of the Institute at a critical period of its history and its subsequent advancement. It is eminently fitting, therefore, that a suitable tribute, in the form of a biographical notice, should appear in these pages in conformity with the resolution of the Board of Managers.

Mr. Sellers was born in Upper Darby, Delaware county, Pa., September 19, 1824; son of John and Elizabeth Sellers, grandson of John and Mary Sellers and of William and Sarah Poole, and a descendant of Samuel Sellers, who, with his brother, George, from Belper, Derbyshire, England, emigrated to this country and arrived in Philadelphia in 1682. George died unmarried. The marriage of Samuel Sellers and Anna Gibbons is the first recorded in Darby meeting of Friends. He took up a tract of land in Upper Darby, Delaware county, under Penn's Patent. This property has remained in possession of his descendants to the present generation, and on a portion of it is the house in which the parents of William Sellers resided when he was born. His ancestors have had a long and memorable connection with science. From the organization of the American Philosophical Society some one of his family has always been a member of it. His paternal grandfather, John Sellers, then a member of Assembly of Pennsylvania, was appointed by this society in con-

nection with three other members, to observe the transit of Venus in 1761, and his maternal grandfather, William Poole, came from England to observe the same transit and remained here.

William Sellers was educated at a private school, built and maintained by his father and two relatives for the education of their children. He was apprenticed to the machinist's trade with his uncle, John Morton Poole, of Wilmington, Del., for nearly seven years.

After he was twenty-one years of age, in 1845, he took charge of the large machine shop of Fairbanks, Bancroft & Co., in Providence, R. I. In 1848, he commenced the manufacture of machinists' tools and mill gearing, at 30th and Chestnut streets, Philadelphia, and subsequently joined Edward Bancroft, who, in the meantime, had removed from Providence, R. I., to Beach street, Kensington. The new firm was Bancroft & Sellers. Later John Sellers, Jr., was admitted as a partner, and in 1853 the new shop at 16th and Pennsylvania Avenue was ready for occupancy, and the firm removed to that site. Mr. Bancroft died about 1856, and the firm became William Sellers & Co. In 1886 the corporation of William Sellers & Co., Incorporated, was established, with William Sellers as President.

In 1868 he formed the Edgmoor Iron Co., of which he was the President. This company furnished all the iron structural material for the Centennial Exhibition buildings, and also furnished all the structural material used in the Brooklyn Bridge, which they built, with the exception of the suspension cables, supplied by the Roeblings. This bridge was the first in which steel eye-bars were used. At that time the Edgmoor was the largest plant in the world for building bridges and other structures of iron and steel.

In 1873 Mr. Sellers became President of the Midvale Steel Co., Nicetown, Phila., which he subsequently reorganized, and under his management became the first successful producer of material required by the Government for its steel cannon.

The development of the business of the Edgmoor Iron Co. turned the inventive ability of Mr. Sellers in new directions, and a long series of mechanical devices was evolved to meet the changing requirements of that business. The works were first started to make wrought-iron by mechanical puddling ma-

chinery of a new type, were subsequently changed to a bridge shop, and later a department was created for the manufacture of boilers of various kinds. Each step in this growth called for new machinery and new methods, and throughout the development Mr. Sellers' personality dominated at every step. He was ever ready with suggestions for improvement in plant and in appliances, and he developed many original devices. Some of this machinery followed along accepted lines, but much was original in conception and design. Among the more striking features may be mentioned a comprehensive hydraulic plant for making upset rods and eye bars,—the latter were first made of iron by a welding process and then of steel by upsetting and and flattening, and involved the use of a special and original annealing furnace for very long bars. Again, there were multiple punches and spacing mechanism for rapidly producing plate girder work without templates, hydraulic riveters, cranes, drills, boring machines and many other devices for the rapid and effective production of work. Each step developed new requirements, and each found him ready with suggestions.

Mr. Sellers was not only a maker of machinery. He was a judge of men and moulder of character, and it is worthy of note that in each of the great establishments which he dominated he gathered about him a staff of efficient and loyal subordinates, who earnestly strove to carry out his wishes. His rule was just, but strict and firm, and it developed industry, system, earnestness, order and thoroughness.

It has been our purpose in gathering material for a biographical notice of the career of William Sellers for the pages of this journal, to dwell especially upon his achievements in the immediate line of his profession as an engineer and a successful manufacturer, but apart from these activities Mr. Sellers' interests were varied and his influence on public affairs was extensive. The Pennsylvania limited liability corporation law was enacted largely because of his efforts, and as one of the two vice-presidents of the Board of Finance of the Centennial Exhibition he devoted so much attention to his duties that it has been said of him that "the success of the Exhibition was largely due to his personal efforts."

In his capacity of Trustee of the University of Pennsylvania he served continuously for no less than thirty-seven years. At

the stated meeting of the Board of Trustees, held on February 7th, 1905, the following minute was unanimously adopted and ordered to be spread upon the minutes:

"The Trustees having learned with the deepest sorrow of the death of their late colleague,

WILLIAM SELLERS,

senior member of the Board, hereby record their sense of the loss sustained by them and the University.

"Mr. Sellers entered the Board in 1868, and during his thirty-seven years of continuous and active service the University has become one of the foremost institutions of learning in America. In all these years his interest has been unfailing and his place will be difficult to fill, especially in the place of the engineering schools, to the organization and development of which his knowledge and experience were so valuable.

"In expressing their personal loss, the Trustees offer their respectful sympathy to Mrs. Sellers and other members of his family."

At the outbreak of the Civil War, Mr. Sellers took an active part in organizing public opinion and in enlisting troops for the Union cause. He was one of the original charter members of the Union Club, formed by a few of the leading patriotic citizens of Philadelphia, out of which afterwards grew the Union League.

In 1864 he was elected a member of the Philosophical Society, and in 1873 became a member of the Academy of Natural Sciences, serving for many years on the Finance Committee; he was a member of the Institute of Mechanical Engineers; he was a Commissioner of Fairmount Park from 1867 to 1872; he was a member of the Institute of Mechanical Engineers of Great Britain, the Iron and Steel Institute of Great Britain, a corresponding member of the Société d'encouragement pour L'Industrie Nationale, in Paris, and at the close of the Paris Exposition, in 1889, the decoration of Chevalier de la Legion d' Honneur was conferred upon him. In addition to the foregoing, he was a member of the American Society of Civil Engineers, the American Society of Mechanical Engineers, the

Philadelphia Contributionship and numerous other associations.

As a designer of machinery, William Sellers had certain well defined ideas. Beauty of line and grace of form were insisted on, and he early adopted, if he did not invent, the dull lead tint now known as "machine gray," which has now almost entirely supplanted the reds and greens and blacks of the early builders. Fitness for the purpose intended, as he saw it, was the keynote, and he had as much horror of unnecessary weight as he had of any other defect in proportion. In construction nothing suited him but the best. He was never deterred by consideration of cost if he saw a way of improving in design or construction. Absolute honesty of purpose was his dominant characteristic, and he would tolerate no deviation from the standard of workmanship, no matter how tempting might be the occasion. There was no thought of patching defects in workmanship or material. Nothing was "good enough" unless it was perfect.* Jealous of his reputation, he set a high standard and followed it undeviatingly. He had to a wonderful degree the courage of conviction and would follow out his own conclusions without hesitation in the face of adverse opinion. In fact, opinions had very little weight with him in professional matters, but he would always listen to reasons, and if the reasons appealed to him he would abandon preconceived convictions readily and without apparent regret. He used to say that he had no "pride of invention," and would readily give up an idea on which he had long labored if convinced that something else offered was better.

As illustrating William Sellers' mechanical ingenuity and fertility of resources it may be noted that he was granted about ninety U. S. patents, either alone or in conjunction with others, the earliest was granted in 1857; and that he had patents pending when he died. These numerous patents granted to him alone, or in association with co-inventors, cover a great variety of subjects—machine tools, injectors, rifling machine, riveters, boilers, hydraulic machinery of various sorts, furnaces, hoists,

*On one occasion while conducting a friend, who was also engaged in the iron business, through the works, the latter commented on the absence of any bad castings, and asked what method was adopted to prevent their occurrence. "We throw them away," was the reply.

cranes, steam hammers, steam engines, ordnance, turntables, pumps, &c. He also obtained many patents in foreign lands. Probably the best known of his inventions is the spiral-gear planer drive, in which the table or platen is moved back and forth by a multi-thread screw on an inclined shaft engaging with a rack on the under surface of the table—a device giving the smoothness of a screw drive coupled with the convenience and efficiency of the usual spur-gear arrangement while permitting a stronger bed framing. This entirely new device proved from the first a great improvement over existing methods, and remains to this day unexcelled. It was patented in 1862.

Mr. Frederick A. Halsey has aptly defined the late William Sellers' status as an engineer in the following words:

"Mr. Sellers has been called the Whitworth of America, the work of the two men being largely on parallel lines and their influence in England and the United States being substantially the same. The merit of Mr. Sellers' work is scarcely less than that of Mr. (Sir Joseph) Whitworth, and when considered in connection with the greater difficulties to be met, it is perhaps even greater. The machine building industry in this country was then in a far more primitive condition than in England; the soil of the country was much less receptive of those advanced ideas which form the foundation of Mr. Sellers' work. His work was from the beginning strikingly original, so much so that to those whose ideas were based upon the undeveloped taste of that time they seemed in many cases almost outre. The writer recently saw, still in use, one of the early special lathes designed by Mr. Sellers for turning railway axles, and so entirely different was it from any form of lathe made at that time that it could scarcely have failed to impress the general observer as a simple oddity. As a matter of fact, it was obviously the result of the keenest analysis of the work to be done and of the strains to be carried by the machine, and the result was simply an adaptation of the form of the machine to these strains—little less than a stroke of genius. While, of course, these machines have been improved and made capable of a much larger output than this early machine of Mr. Sellers', it is nevertheless not exaggerating to say that its outlines form to-day a model.

"It was this adaptation of the forms of his machine to the strains to be carried by them that formed the keynote of Mr. Sellers' method of design, and it was the fact that machines were then designed regardless of such principles that led his forms to appear so strange to those who looked upon the prevailing forms as suitable. Mr. Sellers' methods, however, were soon followed by other designers, and it is safe to say that, so far as modern machines are better in this respect than those of half a century ago, the result is very largely due to the influence of Mr. Sellers' work. This influence is seen more and more in connection with the most recent designs of machines. The influence of tradition is far stronger in connection with these machines (which in a sense became standard many years ago), than those of recent origin, and it is therefore a curious fact that the most modern outlines are seen in machines upon which the opportunity for improvement has prevailed the longest.

"Of his individual achievements Mr. Sellers' name is best known in connection with the Sellers or United States Standard Screw-thread, which he published in a paper read before the Franklin Institute in 1864, at which time he was President of the Institute. A similar effort towards standardization had been previously made by Sir Joseph Whitworth, and Mr. Sellers' work was no doubt inspired by that of Whitworth. The leading differences between the Sellers and Whitworth forms lie in the angle of the thread and in the fact that it has a flat top and bottom instead of a round top and bottom. There has been much discussion regarding the merits of these two forms, of which both have their advantages, but it is safe to say that from the strictly practical standpoint (of getting the standard generally adopted) the Sellers form is the only one which would have had any chance of general adoption in this country at that time. It had the commanding merit that it could be made with a common lathe tool, made in the shop where used, whereas the Whitworth form required a special tool which must be bought from a maker. In addition to the smaller tendency to respect and follow authority in this country as compared with England lay the physical obstacle due to the widely scattered mechanical centers of the country, the effect of which could only have been to defeat standardization should the proposed standard involve

the purchase of special tools for thread cutting. How much of an influence this may have had with Mr. Sellers the writer does not know, but it may well have had a commanding influence."

It has been truly said of William Sellers that he had "the courage of his convictions," and this prominent trait of his character is illustrated in the following incident:

In 1890, the Navy Department of the United States Government, at Washington, sent to leading manufacturers of machine tools elaborate specifications for an eight-foot turning and boring lathe for sixteen-inch steel cannon. This was a leviathan lathe; some idea of its dimensions may be gained when it is stated that the main bed was 73 feet 10¾ inches long and 9 feet wide, the extension bed for carrying the boring arrangement was 53 feet 5 inches long, and 5 feet 2 inches wide, making a total length of 128 feet 3¾ inches.

The Government engineers designed this gigantic machine. Mr. Sellers did not approve of their designs and refused to bid upon them; but he caused new designs to be drawn embodying new principles, differing radically from the Government's drawings. On a day appointed, Mr. Sellers appeared in person and explained his design to the Board of Engineers in Washington, pointing out the merits of his plans, and so thoroughly convinced the Board of their superiority that they adopted the Sellers' plans and discarded their own. This great lathe was built by William Sellers & Co., Incorp., and installed in the Naval Gun Factory in Washington, D. C., where it has attracted the attention and admiration of engineers from all parts of the world. The total weight of this machine was about 500,000 pounds.

During a visit to England, in 1860, the attention of Mr. Sellers was called by Sharp, Stewart & Co., of Manchester, to the Giffard Injector for feeding steam boilers, a model of which had been sent by Flaud et Cie., of Paris, for the purpose of interesting English manufacturers. The device was crude in design, and was generally regarded as a mechanical paradox and an interesting but unpractical toy; it contained, however, the elements of a novel principle, and Mr. Sellers' immediate estimate of the value of the invention evinces the accuracy of his judg-

ment. American rights were at once obtained and royalties paid to Sharp, Stewart & Co., until the expiration of the United States patents.

The same year a special department devoted to the manufacture was added to the plant of William Sellers & Co., and the first injectors were made from French drawings and patterns. Modifications of the original design were introduced to adapt it to the American market, and the present experimental department established to eradicate defects of construction and to obtain a more complete development of the principle. The necessity for automatic adjustment was soon observed, and Mr. Sellers invented and patented, in 1865, the self-adjusting combining tube, which automatically adjusted the supply of water to meet the requirements of varying steam pressures, and improved forms bearing patent dates of 1876 and 1878 are still largely used. Other interests diverted the trend of Mr. Sellers' inventive ability into other channels, and in his later years further experimental work was placed in the hands of Mr. Strickland L. Kneass, but he always retained his deep interest in the subject. In 1888, the self-acting form, devised and patented by Mr. Kneass, was introduced, specially adapted to the high boiler pressure carried on locomotive boilers, and met with immediate acceptance, being adopted by most of the railways of France as the standard, so that injectors bearing William Sellers' name supplanted Giffard's in the country of the inventor, besides being used in almost every country and colony of the globe. In fact, it may be added, that his name is as closely associated with the highest development of the locomotive injector as it has been with the perfection of machine tools or the standard screw thread.

Mr. S. M. Vauclain, Superintendent of the Baldwin Locomotive Works, sends us, as this goes to print, the following appreciative letter:

"It is impossible for me to put in writing exactly my estimation of the late William Sellers. To me he always has been the acme of eminence in the machine tool section of mechanical engineering.

"His productions were always the very best of their respective kind, and as he once very quietly remarked, 'One might object to the price, but never would to the machine.'

"An acquaintance of over twenty years brought him very near to me—the wisdom of his counsel, the excellence of his judgment and his absolute honesty in all things placed him upon a pedestal far above others in our profession.

"At the time of his death I regarded him as the Grand Old Man of Philadelphia, and the father of the great machine tool industry of the world, and surely no man has as yet done so much to promote the art, or establish fixed principles therein from which it would be suicidal to depart.

"You must bear with me when I tell you how impossible it is to express my appreciation of him as a mechanic, engineer, citizen and friend—when we have the ideal, we find that words are unable to describe. Such a man was William Sellers; his name will ever remain green with those who were his friends, and so fortunate as to have been his nearest neighbors.

"Yours truly,

"S. M. VAUCLAIN."

Mr. Wilfred Lewis, M.E., offers the following note:

"It was my privilege for over twenty years to be closely in touch with the engineering enterprises of the late William Sellers, and having contributed perhaps as much as anybody to the scrap-heap out of which his genius drew forth many fruitful results, I can speak of the man and his work from intimate personal knowledge.

"He was an indefatigable worker, and concentrated all his energies upon the problem in hand, whatever it might be, going into the minutest details, while at the same time he never lost sight of the main object in view nor of the completed mechanism or structure as an harmonious whole. An artistic sense of proportion was always present in his mind, but the foundation for his idea of beauty was fitness. When a thing was right he knew it would look right, and he always sought the most direct means to an end as his ideal of mechanical perfection. Endowed with a fertile imagination and strong common sense, he made many useful inventions, and few if any of the sort whose chief merit lies in the ingenuity displayed. It has been truly said that he had no pride of invention, for he was always ready to accept the suggestions of others and put aside his own ideas when it seemed wiser to discard them. What he stood for was

the best to be gathered from any source, and his own contribution to a successful issue was as often in the shape of well directed criticism as in that of actual invention. He was quick to appreciate a good suggestion and as quick to condemn a bad one, and I think everyone who worked for Mr. Sellers felt inspired to do his best by the knowledge that his efforts would stand or fall on their own merits in the eyes of an impartial critic. He was patient, tolerant and kind to honest effort along the lines laid down by him for development, but as inflexible as steel to any departure from those lines until he was satisfied of their futility.

"He knew how to give an order and exact obedience, and only to those who showed the capacity to obey did he extend the authority to direct the management of his affairs, while over all he never failed to exercise a masterly control.

"Of commanding presence and stern appearance, he was nevertheless approachable on any subject and always ready to render a decision upon any question that might arise. When in doubt everyone knew where to turn for guidance, and with apparently little effort this captain of industry kept his forces busy within clearly defined lines. His decision of character was one of the strongest elements in his success, and a purpose once formed was carried through to its logical conclusion regardless of obstacles, the sweeping away of which seemed to be a delight.

"In many directions he was a pioneer inventor, and the high standard of machine construction in America may be said to have been set by William Sellers. The best that could be achieved was never too good for him, and no expense was spared to keep ahead of all competitors in design and construction. This supreme excellence may have opened the door to successful competition, but it emphasizes rather than detracts from the recognized position of William Sellers as the greatest tool builder of his day and generation.

"WILFRED LEWIS."

Mr. Strickland L. Kneass, C.E., contributes the following interesting account of some experiments made at the Naval Gun Factory, in Washington, D. C., carrying out to a successful conclusion William Sellers' new projects involving radical

changes in construction of "built up" steel cannon and the method of assembling and dis-assembling the various parts:

"While designing and manufacturing the large lathes and boring machines for the Naval Gun Factory, Mr. Sellers also became interested in the problem of gun construction. He carefully analyzed existing methods and determined upon a bold and simple design, reducing the number of parts and increasing the longitudinal strength and accuracy during fire. He contemplated substituting for the breech and chase rings one continuous inner jacket and a superimposed outer jacket, reducing the essential parts from thirteen to three.

"With existing apparatus, this was impossible, and Mr. Sellers designed and built an assembling furnace for an 8" Breech Loading Rifle, the tube and jackets of which were made at Washington. He placed the experimental work in the hands of the writer, and in 1891 tests were made with models upon a scale of 1-12, which showed conclusively that jackets could not only be shrunk in place, but could also be removed by Mr. Sellers' method, indicating the possibility of dis-assembling a gun and replacing a tube eroded by powder action. The scheme was brilliant, but required new and specially-designed heating furnaces, rapid cooling stands and pyrometers for determining the internal temperature of the tube and jackets at various points. Each part of the problem was attacked in an original and ingenious manner, and his complete apparatus was used by the writer at the Naval Gun Factory, at Washington, during the summer of 1894. As was to be expected with a problem involving such difficulties, further experimental work was required, but on August 1st, 1904, the inner jacket 21 ft. 9" was dropped over the steel gun tube 25 ft. 4" long and shrunk to place. The parts of the gun were then removed from the furnace, and after cooling to normal temperature were again placed in the heating furnace, and the same operation was accomplished with the outer jacket.

"After an interval of nearly two years, in January, 1897, the dis-assembling was attempted; it was not surprising that with an operation of such paramount difficulty, the weight of the gun being 31,975 pounds, and that of the furnace 35,000 pounds, further experimental work was required, especially as most of the practical men connected with the Gun Factory de-

clared the feat to be impossible. The total area of contact of the inner jacket and tube was 85 sq. ft., and the bore before assembling was 0.019" smaller than the diameter of the tube, exerting a contact pressure when shrunk to place of about 50,000 pounds per sq. in. After several trials, in February, 1897, the tube was successfully removed from the inner jacket, and in the following month the outer jacket was taken off, justifying Mr. Sellers' faith in his scheme and rendering possible the construction and dis-assembling of large breech loading rifles at considerable saving to the Government."

STRICKLAND L. KNEASS.

The Secretary of the Franklin Institute says:

"Mr. Sellers' relations with the Franklin Institute began with his election as a member, in 1847, and continued uninterruptedly until his death. He served as a member of the Board of Managers from 1857 to 1861, and again from 1864 to 1892, inclusive. His services during a period of severe financial stress from which the Institute suffered in the early sixties, as the consequence of an unfortunate investment of its funds, will ever be held in grateful remembrance.

"It was largely due to the personal efforts of a special committee, of which he was a member, that a considerable sum was subscribed to free the Institute from its most pressing obligations, to which fund he was likewise a liberal contributor.

"After the reorganization of the Institute, in 1864, under an amended charter, in which movement he was an active participant, he became the first President of the reorganized body, serving in this office from 1864 to 1867, and his administration of its affairs was signalized by notable increase in its activity. Perhaps the most prominent incident of his administration was the formulation, by a special committee, of which he was the chairman, of a uniform system of screw threads, which was presented in the form of a report read at the stated meeting of the Institute, held September 15, 1864 (see the *Journal*, January, 1865). This report, with its suggestions, was approved by the Institute, and within a comparatively few years, the system of screw threads proposed therein, was officially adopted by the United States Government in its workshops, by the leading railroad companies, prominent machine tool builders and oth-

ers under the various names of United States, Sellers or Franklin Institute system. It is now in universal use throughout the country."

Other attempts had been made to standardize threads for screws, but William Sellers was the first to devise a set of proportions and reduce them to formulæ so that the proper size, shape and pitch for a given diameter of screw can be determined without comparison with a pre-determined list. The angle and the truncated form of screw thread proposed by Mr. Sellers, which became the standard for the United States, were adopted by the International Congress for "L' Unification Des Filetages et des Gauges," held at Zurich, in October, 1901.

In reviewing the life and attainments of William Sellers, it is proper to allude to the numerous awards given at various international expositions to the house of which he was the senior, and after incorporation the President, as well as to the honors conferred upon him as an individual in recognition of his genius as an inventor and constructor of machinery.

At Vienna, in 1873, in addition to five bronze medals, there was awarded the GRAND MEDAL OF HONOR upon the following recommendation of the jury, viz.: "SELLERS. For pre-eminent achievements in the invention and construction of machine tools, many of which have been adopted as patterns by the constructors of tools in all countries." This diploma was awarded exclusively by the Council of Presidents and was, as therein stated: "Designed to bear the character of peculiar distinction for eminent merits in the domain of science and its application to the education of the people, and the advancement of the intellectual, moral and material welfare of man."

The following extract from the report of the judges appointed for the examination of Group XXI (machine tools) at the Centennial Exhibition will suffice to indicate the nature of the award given to William Sellers & Co. for their exhibits.

"The undersigned, having examined the products herein described, respectfully recommend the same to the United States Centennial Commission for award for the following reasons, viz.:

"For a remarkable collection of machine tools for working metal. This exhibit, when considered in regard to its extent and value, its extraordinary variety and general excellence, as

also for the large amount of originality that is shown in the numerous devices that are introduced, is probably without a parallel in the past history of international exhibitions, and, taken as a whole is worthy of the highest honor that can be conferred. Besides, it is thoroughly national in its characteristics and pre-eminently worthy of the United States and of the grand occasion of the Centennial Exposition. Every single machine, tool or piece of apparatus that is displayed in this vast offering, would, for itself, command the strongest recommendation for an award, even if it stood alone as a unit; but here every unit is surrounded by thirty-three distinct machines, each one being of the highest standard in its particular class. The whole of these machines are characterized by extreme refinement in detail; by the superior quality of the material employed in their construction; by first-class workmanship, both in regard to nice fitting and precision, and for the mathematical accuracy of all the parts; by the beautiful outlines that are imparted to each structure; by the correct proportions that have been worked out in the determining of strength and form; and the disposal of material to take its full share of duty. For the scientific skill displayed in the application of mechanical force, for the daring shown in fearlesly breaking though the trammels of the past by introducing variously constructed devices and arrangements of gearing for the transmission of power in more direct course to the point of action, yet maintaining correct construction mechanically, and without departure from true principles. As it is impossible to realize the full measure of such refined mechanical, scientific and artistic merit, by the foregoing remarks, it is deemed necessary to enumerate briefly some of the more prominent points in the several machines, both in justice to the exhibitor and to the judges."

Here followed a description of twenty-two distinct exhibits.

Remarkable as was the foregoing tribute to an American exhibit of machine tools, it was still more gratifying from the fact the jury was composed of men of various nations having international reputations, as the following list of names will show:

John Anderson, LL.D., C.E., etc., Woolwich Arsenal, Great Britain.

Prof. C. A. Angstrom.....Sweden.

August Gobert, Jr.....Belgium.
F. Reifer.....Austria.
M. Le Commandant F. Perrier.....France.
George H. Blelock.....Springfield, Mass.
N. F. Durfee.....New York.
Professor J. A. Anderson.....Manhattan, Kansas.

Dr. John Anderson (Mechanical head of Woolwich Arsenal) was the chairman of this group.

To give detailed accounts of all the awards made in past years to William Sellers & Co. at the various national and international expositions would necessarily extend this article beyond the prescribed limits. The following list must therefore suffice without further comment thereon:

AWARDS TO WILLIAM SELLERS & CO., INCORP.

1854—Franklin Institute, Philadelphia, Silver Medal.
1857—Maryland Institute, Baltimore, Silver Medal.
1867—World's Fair, Paris, Gold Medal.
1869—American Institute, New York, Six Medals.
1873—World's Fair, Vienna, Five Medals and Grand Diploma of Honor.
1876—Centennial Exhibition, Five Medals and Report of International Jury.
1880—Imperial Technological Society, St. Petersburg, One Medal.
1883—Exhibition of Railway Appliances, Chicago, One Gold Medal, Four Silver Medals.
1889—World's Fair, Paris, Grand Prize.
1904—Louisiana Purchase Exposition, St. Louis, Grand Prize and Gold Medal.

NOTE.—William Sellers & Co., Incorp., have made no competitive display at any exhibition other than those mentioned above.

At the conclusion of the Louisiana Purchase Exposition, Mr. Sellers was informed by letter from the chief of the Department of Machinery that he had been awarded a "Grand prize as collaborateur in recognition of your (his) genius as a pioneer

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in the development in America of Machine Tools of the highest class." This grand prize is a distinction awarded to a few of the most distinguished men of science, and is quite distinct from the awards given for exhibits at the exposition. Since the death of Mr. Sellers an official card of announcement of this award granted by the International Jury of Awards, has been received from the Secretary of Awards.

Mr. Sellers was a man of iron constitution and commanding presence, his words were direct and forcible and his manner was gracious. His opinions and counsel were sought in times of difficulty by men in all walks of life, and his judgment was regarded as of the greatest value, not only in engineering matters, but in civic and governmental affairs of importance. He never sought nor accepted public office.

Soon after the visit of the Iron and Steel Institute of Great Britain to Philadelphia, in 1904, Mr. Sellers received the following letter:

"We, the President, Council and members of the Iron and Steel Institute, desire to convey to William Sellers our sincere and cordial thanks for the very great personal services assiduously rendered with such exceeding kindness and marked courtesy to the members of the Institute during their visit to the United States of America, in 1904."

Signed by the President, Andrew Carnegie, and others.

Several years ago the late Sir Joseph Whitworth said of William Sellers in conversation, that he was "the greatest mechanical engineer in the world." This was a high tribute, indeed, for Sir Joseph Whitworth was, himself, one of the leading mechanical engineers in the world.

Mr. Sellers died January 24, 1905, in the 81st year of his age.

ALEXANDER E. OUTERBRIDGE, JR.,
COLEMAN SELLERS, JR., } Committee.

AMBER.

The Prussian Government collects over $380,000 annually as revenue from the amber mines of Palmicken. From 1803 to 1811 the industry had to receive a subsidy from the Government; now it is self-supporting. In the twenty years from 1883 to 1902 the Palmicken mines produced 8,458 metric tons of amber, the record being established in the last three years.

The value of amber used in America last year was $210,709, making it the second largest consumer in the world. Besides smoking materials, ornamental beads and other articles are made from imported amber.

RAMSAY ON RADIUM.

In *Harper's Magazine* for December, Sir William Ramsay, the discoverer of helium, writes of 'Radium and its products." The results of Ramsay's work have been almost a justification of the idea of alchemy—the transmutation of one metal into another:

"The chemical examination of the products of change of radium leads to a hypothesis as regards the constitution of radium and similar elements, which was first put forward by Rutherford and Soddy. It is that atoms of elements of high atomic weight, such as radium, uranium, thorium and the suspected elements—polonium and actinium—are unstable; that they undergo spontaneous change into other forms of matter, themselves radioactive, and themselves unstable; and that, finally, elements are produced which, on account of their non-radioactivity, are as a rule impossible to recognize, for their minute amount precludes the application of any ordinary test with success. The recognition of helium, however, which is comparatively easy of detection, lends great support to this hypothesis.

"The natural question which suggests itself is: Are other elements undergoing similar changes? Can it be that their rate of change is so slow that it cannot be detected? Prof. J. J. Thomson has attempted to answer this question, and he has found that many ordinary elements are faintly radioactive; but the answer is still incomplete, for, first, radium is so enormously radioactive that the merest trace of one of its salts in the salt of another element would produce such radioactivity; and, second, it is not proved that radioactivity is an invariable accompaniment of such change; or, again, it may be evolved so slowly as to escape detection. A lump of coal, for example, is slowly being oxidized by the oxygen of the air; oxidation is attended by a rise of temperature, but the most delicate thermometer would detect no difference between the temperature of a lump of coal and that of the surrounding air, for the rate of oxidation is so slow."

SUBWAY ENGINEERING IN 1904.

Probably the most important event in the world of civil engineering during the year was the opening of the Rapid Transit Subway in New York. While this is not by any means the first subway built to accommodate the passenger traffic of a large city, it is certainly the first attempt to provide a genuine express service over a four-track tunnel road. The system has been in operation long enough to prove that it is possible to run an underground service of fast trains under short headway with a minimum of risk and a maximum of punctuality and general comfort—all below the surface of the ground and entirely independent of street traffic. The past year has seen the opening of the unique system of freight subway, which has been built below the business portion of the city of Chicago. It includes a series of trunk lines running beneath the principal streets, with feeder lines extending below the cross streets, whereby freight may be taken from the terminal stations of the great roads that center in Chicago direct to the shipping floors of the various business houses. Twenty miles out of the sixty miles of tunnels contemplated by this scheme have been completed.—*Scientific American.*

CHEMICAL SECTION

Stated Meeting, held Thursday, March 12, 1904.

On the Distribution of Velocity Among the Members of a Group of Gas Molecules.

By G. H. Meeker, M.S., Ph.D.,

Professor of Chemistry, Medico-Chirurgical College, Philadelphia.

[Abstract:—This paper is an investigation of a problem in the kinetic theory of gases. Six arguments are given—all leading to the same conclusion: viz., That in a group of gas molecules of equal mass, in a steady state, at constant temperature, the molecular velocities are sensibly equal; and do not vary from zero to infinity, as is generally assumed by writers in the field of the kinetic theory of gases.—The Editor.]

Statement of the Propositions.—While many eminent investigators have given us the results of their mathematical researches in the field of the kinetic theory of gases, it would appear, from what is to be said below, that they have too lightly considered the question of the distribution of velocities among the members of a group of gas molecules, while the gas remains at constant temperature. It seems to have been quite universally assumed as a starting point that, given a gas at constant temperature and composed of a congeries of molecules of equal mass, then (while the velocities in the group of molecules preserve a certain average value—*i. e.*, the square root of the average of the squares of all the velocities—named by Maxwell, the velocity of mean square) the individual molecules have very varying velocities. Thus, Maxwell (Enc. Brit., 9th Ed., III, 40) says that whereas Clausius in his earlier work had assumed the molecular velocities to be equal, Maxwell has shown that the velocities vary from 0 to ∞. Maxwell says also (Theory of Heat, 10th Ed., 315, 316, 338) "Let us suppose a number of molecules in motion—the first thing we notice about this moving system is that even if all the molecules have the same velocity originally, their encounters will produce an inequality of velocity. It appears then that of the molecules composing the system some are moving very slowly, a few are

moving with enormous velocities, and the greater number with intermediate velocities . . . Let us suppose a vessel . . . full of air at constant temperature . . . divided into two portions, A and B, by a division in which there is a small hole, and that a being who can see the individual molecules, opens and closes this hole so as to allow only the swifter molecules to pass from A to B, and only the slower ones to pass from B to A. He will thus, without expenditure of work, raise the temperature of B and lower that of A, in contradiction to the second law of Thermodynamics," "Maxwell's demons" (as the above beings are commonly designated) have become famous.

These statements from Maxwell's works serve to outline the prevalent ideas of the day as to the distribution of molecular velocities among the members of a group of like molecules in a gas at constant temperature.

It is the purpose of this paper to call attention to certain reasons for thinking that the opinions just sketched are erroneous. The investigation may be conducted from the mechanical or from the experimental standpoint. We have confined ourselves, in the main, to the experimental point of view; and will begin in that way—endeavoring to show that the theory of variable velocities is not in harmony with certain observed properties of matter.

Let it be assumed that the prevailing ideas of the day concerning the corpuscular nature of gases are generally correct. Let the problem be to prove the falsity of the first and the truth of the second of the following two propositions:

PROPOSITION I.—"In a group of equal gas molecules in a steady state, at constant temperature, the individual molecules have very varying velocities—though the velocity of mean square remains constant."

PROPOSITION II.—"In a group of equal gas molecules in a steady state, at constant temperature, the individual molecules all have the same (or nearly the same) velocity."

For the sake of brevity, let Proposition I be called the theory of variable velocity; and let Proposition II be called the theory of uniform velocity. We will now present what seem to be six valid proofs of the truth of the theory of uniform velocity:

One Proof.—One of the best known of the experimentally determined laws of gases is that of Graham. Equation (1) states Graham's law—

$$(1)\ R : r = \sqrt{d} : \sqrt{D}$$

Where R is the volume rate of the diffusion of a gas having a density, D, and a molecular mass, M; and where, r, is the volume rate of diffusion of another gas, having a density, d, and a molecular mass, m—both gases being at the same temperature and pressure.

Graham's law is very approximately true; and maintains not only when the two gases diffuse into each other; but also, when, after mixture with each other in equal volumes, they diffuse into a third gas.

Another gas law, that of Avogadro, is stated in equation (2).

$$(2)\ M : m = D : d$$

Since the gases are at the same temperature the kinetic energies per molecule are equal—it being understood that the expression "kinetic energy per molecule" is to be interpreted as meaning either a fixed property of each molecule if the theory of uniform velocity be true; or a certain mean quantity if the theory of variable velocity be true. From the equality of molecular kinetic energies, at uniform temperature, we have equation (3).

$$(3)\ \tfrac{1}{2} MV^2 = \tfrac{1}{2} mv^2$$

in which V and v are the respective velocities of M and m.

Hence, $(4)\ MV^2 = mv^2$

and, $(5)\ M : m = v^2 : V^2$

and, $(6)\ \sqrt{M} : \sqrt{m} = v : V$

But from (2) we have—

$$(7)\ \sqrt{M} : \sqrt{m} = \sqrt{D} : \sqrt{d}$$

Hence, $(8)\ \sqrt{D} : \sqrt{d} = v : V$

and, comparing (1) and (8) we have—

$$(9)\ R : r = V : v$$

Equation (9) thus gives us the result that, temperature and pressure being constant, two gases diffuse into each other; or into a third gas at volume rates directly proportional to their molecular velocities. But, temperature and pressure being constant, equal volumes of all gases contain equal numbers of molecules. We can, therefore, restate Graham's law as in equation (10)—

$$(10)\ N : n = V : v$$

in which N and n are the numbers of molecules, of velocity V and v respectively, passing in opposite directions across a unit plane in unit time.

It is possible to state the law of diffusion still more rigidly. In figure 1, let the rectangle represent a vessel containing

gases, G and g, corresponding to N and n respectively; and let these gases be separated by an imaginary plane.

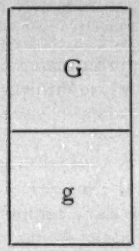

Figure 1.

Under the conditions given, and even though G be less dense than g, the molecules of the two gases begin to intermingle spontaneously. This intermingling or diffusion proceeds continuously until there has resulted throughout the vessel a uniform mixture of the two gases. This condition persists.

Now, since equal volumes of the mixed gas contain equal numbers of molecules, it follows that in any unit volume of the vessel there are as many molecules of either gas as there are molecules of that gas in any other unit volume of the vessel. The molecules continuing in motion, we have still enduring that migratory process which had produced the special equilibrium just noted. The equilibrium established is therefore a mobile equilibrium—conditioned upon the fact that across any unit plane in the vessel, and in unit time, there pass in opposite direction equivalent streams of molecules. Equation (11) therefore states the condition of equilibrium in diffusion; and is more rigid than Graham's law.

$$(11)\quad N : n = \Sigma V : \sigma v$$

in which Σ and σ are, in unit volume, the respective numbers of molecules, having velocity V and v.

Stating equation (11) verbally, it would read: "The number of molecules passing in one direction in unit time across unit plane is proportional to the number of molecules in unit volume multiplied by the molecular velocity." This result is, of course, exactly what might have been rationally expected; but it has.

as just developed, the greater advantage of experimental demonstration.

Cor. α. It will be seen from equation (11) that so long as Σ and σ remain sensibly equal, N and n are proportional to V and v only. Graham's experiments were of this type.

Cor. β. In the law of diffusion, as just developed, the constant of proportion is $\frac{1}{6}$ (see equation (14)). Hence the law may be stated is in equation (12)—

$$(12)\quad N = \tfrac{1}{6}\Sigma V$$

Very direct evidence of the truth of the theory of uniform velocity is to be found by an inspection of equation (11). In a mixture of two gases, the mobile diffusion equilibrium is known to be established when equal volumes have identical composition. It is this fact that proves the validity of the factors Σ and σ in equation (11). The validity of the factors V and v is proven by our interpretation of Graham's experiments, and by the rational character of the factors. True, the values V and v may be merely mean values; but, rationally, they must be arithmetic means. In a group of molecules having variable velocity, the arithmetic mean velocity does not coincide with the velocity of mean square; and hence the theory of variable velocity is discredited by the experimentally determined diffusion equilibrium. (See also the closely related discussion on page 394 of the theory of the pressure of a gas.)

Further Evidence.—With the help of the foregoing equation, we may now proceed to another experiment, which will lead to the same conclusion as that just stated. Imagine a rectangular prismatic vessel, represented by the diagram (Figure 1), into which is placed a volume of oxygen, G; and a mixture of equal volumes of hydrogen and carbon dioxide, g — G and g being separated by an imaginary plane. A process of diffusion would ensue—in which process molecules of hydrogen and molecules of carbon dioxide would pass into region G, while molecules of oxygen would pass into region g. But, as the velocity of the hydrogen molecules is greater that that of the carbon dioxide molecules, it follows that after a certain interval of time we would have in G more molecules of hydrogen than of carbon dioxide (equation (10)). It is therefore possible, by a process of diffusion, to divide a mass of gas having molecules of unequal velocity, into two portions—one portion being richer

than the original gas in those molecules having the higher velocities; and the other portion being richer than the original gas in those molecules having the lower velocities.

Let the last experiment be varied by making G a certain volume of hydrogen; and g a certain volume of carbon dioxide. Now, if the hydrogen molecules have very varying velocities, it would follow that those hydrogen molecules having the higher velocities would begin to pass into the region g in greater profusion than those hydrogen molecules having the lower velocities. Also, those carbon dioxide molecules having the higher velocities would begin to pass into the region of G in greater profusion than those carbon dioxide molecules having the lower velocities. But there would be a greater number of hydrogen molecules passing into g per unit time than of carbon dioxide molecules passing into G in unit time. Thus: in the language of the theory of variable velocity, not only is the velocity of mean square greater for hydrogen molecules than for carbon dioxide molecules; but also there must be per unit volume of hydrogen, a greater number of molecules with velocities above a certain reference velocity, than of such molecules per unit volume of carbon dioxide. The mean kinetic energy of agitation of the molecules in region G would therefore decrease; while the mean kinetic energy of agitation of the molecules in region g would experience a proportionate increase. But this is the same as saying that the temperature of region G would fall; and the temperature of region g would rise. It is to be remembered that our last statement is conditioned upon the assumption that in a simple gas at constant temperature, the molecules have very varying velocities. If we assume, on the contrary, that the molecules have sensibly equal velocities, no observable temperature change could result. Here, then, is a means for experimentally determining which of the two assumptions is the correct one—for we can perform the experiment under such conditions that any temperature changes will be observed. If no temperature changes occur, we must conclude that the molecular velocities are sensibly uniform. If the indicated temperature changes do occur, we must conclude that the molecular velocities vary. I have conducted such an experiment by what would appear to be a satisfactory method; and I find no change in temperature.

The Special Experiment.—The apparatus and its operation are explained by figure 2, which is a schematic sectional elevation.

A, B, C, D is a thin-walled porous earthenware vessel.

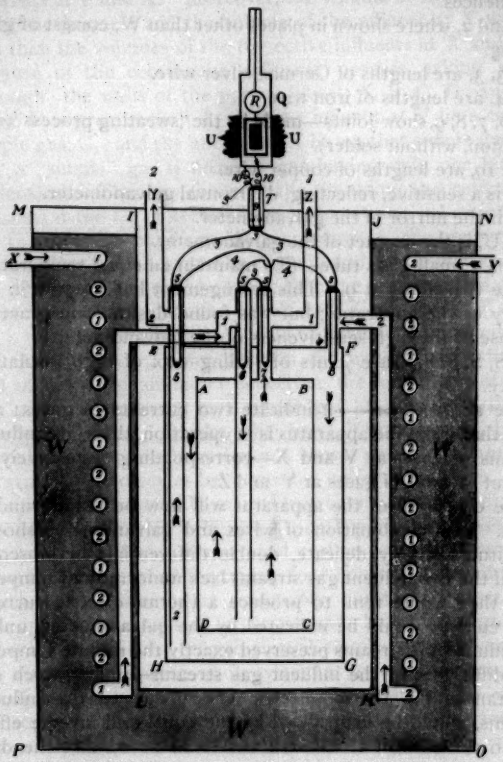

Figure 2.

I, J, K, L " copper vessel,
M, N, O, P " copper vessel,
E, F, G, H " glass vessel,

M, I, J, N " copper and asbestos-board cover,
W, W, W is water.

1 and 2, where shown in W, are two thin walled, small bore, brass tubes. These tubes are coiled, side by side, so as to form two helices.

1 and 2, where shown in places other than W, consist of glass tubing.

3, 3, 3, are lengths of German silver wire.

4, 4, are lengths of iron wire.

5, 6, 7, 8, 9, show joints—made by the "sweating process" (*i. e.*, by fusion, without solder).

10, 10, are lengths of copper wire.

Q, is a sensitive, reflecting, d'Arsonval galvanometer.

R, is the mirror of the galvanometer.

U, U, is the magnet of the galvanometer.

T, is a small glass tube—(To maintain an equal temperature on the two joints at 9. This arrangement has no part in the theory of the apparatus; but was found desirable in practice, because of the high sensitiveness of the galvanometer.)

S, S, S, S, S, S, are joints of sealing wax of high insulating quality.

The arrows (➤➤➤➤) indicate two currents of gases; and show that when the apparatus is in operation, there are influent streams of gases at V and X—corresponding respectively to effluent streams of gases at Y and Z.

The operation of the apparatus will now be readily understood. The combination of wires and galvanometer shown, constitutes a very delicate, double differential thermoscope. For, if the two influent gas streams lack uniformity of temperature, they would tend to produce a thermo-electric current. Such current would be indicated by the galvanometer, unless the effluent gas streams preserved exactly the minute temperature difference of the influent gas streams—under which circumstances the thermo-electric effect, due to the influent streams, would be neutralized by the equal and inverse effect due to the effluent streams. It is to be noted that the difficulty sometimes experienced with thermo-electric couples—because of their relatively slow response—is obviated in the plan adopted here. The couples, being bathed in a continuous stream of gases, have ample time to rise or fall in temperature.

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Let the influent gas at, V, have a density, d; and the influent gas at, X, have a density, D. Let $D > d$. The effluents at Y and Z, because of the passage of the gases through the apparatus, will not have the same composition as their respective influents at V and X. Moreover, the volume of the effluent at Z will be greater; and the volume of the effluent at Y will be less than the volumes of the respective influents at X and V—because of the continuous diffusive process taking place through the walls of the porous vessel, A, B, C, D; and because D is greater than d. Let the influent at V be a certain simple gas, G_1; and the influent at X be another simple gas, G_2. (By a "simple" gas is meant a gas having only one kind of molecules). Then (as shown in the preceding theoretical discussion) if the G_1 molecules have very varying velocities, and the G_2 molecules have very varying velocities, the temperature of the effluent at Z would be higher; and the temperature of the effluent at Y would be lower than the temperatures of the respective influents into the vessels A, B, C, D, and E, F, G, H. Such temperature alteration would be indicated by the galvanometer. Therefore, if we perform the experiment indicated, and obtain a galvanometer deflection, the hypothesis of varying molecular velocity in a simple gas at constant temperature is supported. On the other hand, if no deflection be observed, we must conclude that in a simple gas at constant temperature, the molecules have sensibly uniform velocities.

In my experiments I have used hydrogen and carbon dioxide. The apparatus shown in Figure 2, together with the generators, purifying and drying trains; and certain auxiliary apparatus were allowed to stand for twenty-four hours in a closed room, which was maintained at reasonably constant temperature. The apparatus was tested in various ways by interchanging the influents and also the thermo-electric couples; and by verifying the sensitiveness of the whole system as to minute temperature changes. I have obtained repeatedly the result that the effluent hydrogen stream neither falls in temperature; nor does the effluent stream of carbon dioxide experience a temperature increase.

The auxiliary apparatus, to which reference has been made, consists of a separate metallic water tank capable of being divided into two parts whenever desirable. The hydrogen and

carbon dioxide were passed through coils of small brass pipe, immersed in the water in the tank, before being delivered to the apparatus shown in Figure 2. In this way, the temperatures of the two gases had a preliminary equalization. An indicating manometer system was also arranged, so that, by merely opening and closing cocks, the activity and uniformity of the diffusion could at any time be tested. The experiment itself was conducted at constant pressure—that of the atmosphere at the time of the experiment.

Further Evidence.—It would appear that many well known properties of gases are inconsistent with the theory of variable velocities. It may be advantageous to mention an example or two by way of illustration. It is well known that many gases having polyatomic molecules tend to dissociate sensibly upon sufficient elevation of temperature. In the kinetic theory of gases, an elevation of temperature means an increase in molecular velocity. But the theory of variable velocity requires at all times values for the velocity ranging from zero to infinity (See the quotations from Maxwell and Meyer given in this paper). In such a system the encounters between molecules with relatively high velocities would result in the disruption of those molecules. Gases would therefore exhibit anomalies in density such as have not been observed. True, the slower molecules might be supposed to have a tendency to polymerize. Such supposed compensatory process is made very improbable when judged by the theory of variable velocity itself—for the theory necessitates a greater probability for the very small velocities than for the very great velocities (See Meyer); and this would mean an over-correction by polymerization.

Let us take another pertinent example—typical of many well-known chemic systems: In a vessel, let two volumes of hydrogen be mixed with one of oxygen. Now, if the temperature be elevated to a sufficient degree, in any portion of the vessel, combustion proceeds, explosively, throughout the whole mass of the mixed gases—though no sensible reaction takes place at ordinary atmospheric temperatures. But elevating the temperature means merely increasing the corpuscular kinetic energy; and, therefore, if we have in the mixed gases, at all temperatures, all values for the corpuscular kinetic energy, as

required by the theory of variable velocity, we should get explosive combination between the hydrogen and oxygen at ordinary atmospheric temperatures. Therefore, the known properties of the gas mixture are not in harmony with the theory of variable velocity.

Further Evidence.—Passing from the experimental verification of the theory of uniform velocity, it will now be shown that the same conclusion can be reached by an examination of the theory of variable velocity itself.

In O. E. Meyer's elaborate mathematical work on the kinetic theory of gases, we find that, while in general he employs the theory of variable velocity, he also makes the statements now to follow. (English Edition—pages 368,369, 370, 44, 49.)

"Very many proofs have been given of Maxwell's law. One such proof was attempted in the first edition of this book, wherein the law was put forward as the most probable of all conceivable laws . . . (but) the proof in its first form cannot be admitted as valid, and the doubts thrown upon it by Boltzman and von Kries must be held to be well founded. . . . I will therefore now lay the foundation of this proof in a way which will, I hope, be valid. Maxwell's law of distribution refers to the state which a group of gas molecules finally attains as its state of equilibrium in consequence of their encounters. . . . But, strictly speaking, it can only be reached when the number of gaseous molecules is . . . infinite. . . . if the number of particles is limited, Maxwell's distribution cannot exist at every moment . . . All values between 0 and ∞ occur for the components of velocity . . . the occurrence of the zero value is more frequent than that of any other given value. . . . This conclusion, however, must be false, as it can only extremely seldom happen that a molecule comes to rest in the midst of a swarm of molecules rushing rapidly about."

Meyers attempts to harmonize the uncertainties and contradictions just noted; and his efforts lead him to conclude (p. 52) . . . "That the values of the speed that occur with any considerable frequency are only slightly different from that of greatest probability, whence we might conclude that the idea of the molecules possessing equal speed is really approximately admissible." In other words, if we are to accept Meyer's

words as just given, the theory of variable velocity in the abstract leads to certain difficulties. The methods which appear to him as necessary to be used to clear away these difficulties, only lead to the establishment of the theory of uniform velocity. It would also be very instructive to know the effect of a molecule having an infiinite velocity.

Further Evidence.—The kinetic theory of gases leads to the conclusion (Maxwell—Enc. Brit., 9th Ed., XI, 569, 570, Sec. 39-45) that the pressure, P, exerted by a gas upon unit area of the containing walls, is determined by the following equation:

$$(13)\quad P = \tfrac{1}{3}MNV^2,$$

M is the mass of the molecule; N is the number of molecules in unit volume; V is the molecular velocity.

It would seem entirely admissible, after a cursory inspection of this equation, to say that V^2 *may* be only a mean value; and that among the N molecules concerned, the individuals can exhibit great differences in velocity, while the gas remains in a generally steady state at constant temperature. But before we make such an assertion, we must remember that the value of P is not the only thing to be considered. Certainly the value of P remains unaffected in the premises; but this fact forms no legitimate reason for asserting that the gas can have the property described. Equation (13) is merely the simplified form of equation (14), viz.:

$$(14)\quad P = 2NMV\frac{V}{6}$$

The expression $\frac{V}{6}$ determines the number of molecular impacts on each side of unit cube in unit time by each molecule. This number is obviously functioned directly upon V. Hence it cannot be functioned upon the velocity of mean square unless the velocity of mean square be identical with V. The velocity of mean square is identical with V only when the molecules all have the same velocity. So, again we have the theory of uniform velocity confirmed by internal evidence in the kinetic theory of gases.

Further Evidence.—The theory of variable velocity may logically be divided into two parts—one of which must follow the other in this sequence: First, the proof that in a group of gas molecules the velocities *must* be variable; and, second, the mathematical investigation of the fact thus proved. This

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paper has no reference whatever to the second portion of the theory. The first part of the theory, as thus divided, would seem to be necessarily inductive in character—the proof being drawn from observed properties of matter. If this be so, then, no matter how profound and accurate may be the mathematical deductions of the second portion of the theory, the conclusions will not necessarily describe the properties of gases, except the proof given in the first portion of the theory be correct. We find only one proof, given by Maxwell, that in a group of gas molecules, the velocities must be very variable. In fact, only the merest mention is made of it (See page 383). The same proof is given very clearly in the work of Meyer, to which reference has heretofore been made (Pp. 41 and 42). We quote his words: " . . . if all the molecules had exactly equal speeds at any moment, this distribution of speed would be at once disturbed . . . consider . . . the case of a moving particle being struck perpendicularly to the direction of its motion and so that the direction of the blow passes through its center of mass; then the striking particle will cede part of its speed to the struck particle; which, as it experiences no resistance in the direction of the path it has thus far traversed, will retain its own motion undiminished, and, therefore, receiving in addition a further speed from the striking particle, will move more quickly than before collision, and in changed direction, while the other moves more slowly, since it must lose speed."

It is submitted that this proof is invalid—because the assumption that the struck particle "experiences no resistance in the direction of the path it has thus far traversed," is not in harmony with the facts that molecular action and reaction during any encounter require a certain time for completion; and that during this time interval, cohesion is operative. The cohesion would operate as a resistance, and not only would the struck particle be *pushed* by the striking particle, but also the struck particle would *drag* the striking particle.

A Theory of the Conduction of Heat in Gases.—We further propose, that whenever a previous difference in the molecular kinetic energies exists, then the stresses set up during the time of encounter would result in a torque, tending toward the equalization of the kinetic energies; and that the conduction of heat in gases is so explained.

CHEMICAL EVOLUTION.

The periodic sequence is a wide and valuable arrangement of the chemical elements; but it contains several apparent inconsistencies, not to mention many vacant seats. Among the confusing statements may be mentioned the reversed atomic weights of nickel and cobalt in one group, and of iron and tellurium in another. In the most recent and most accurate atomic-weight determination, nickel certainly is a little below cobalt; yet the chemical relation would seem to reverse this, putting cobalt nearer iron, and nickel nearer copper. Again, tellurium appears to be the homologue of sulphur and selenium; but the atomic weight determinations, while not strictly accordant, yet seem to put tellurium at 128, and above iodine, which is near 127. Now iodine is a well-defined halogen, falling into its place under fluorine, chlorine, and bromine; and tellurium, as mentioned above, seems a well-defined "metallogen." The discrepancies in these cases are not yet explained. They may serve as promising starting points for new discovery. They may involve contamination with small quantities of unknown elements. They may involve the new idea (borrowed from radium chemistry) of atomic disintegration, or concretion. But whatever the explanation, one conception is coming out more clearly with every new fact and theory, namely, the doctrine of the evolution of the chemical elements.

We are familiar with the hoary dignity of the nebular hypothesis, and with the more recent story of organic evolution; but back of the comparatively recent and youthful nebulous whirl—back in what may reasonably be called suns and stars are only cold-storage remnants of celestial history. young—at least in our part of the universe—back there somewhere, the elements were probably evolved from a simple form of matter by a system of their own. Imagination must guide us in reading between the lines of the Periodic Sequence this fascinating story of "the ether babies." Indeed, the first few volumes of this "Descent of the Elements" are missing, but we can fill out the story fairly well There was a something, and it had parts. It was hot, hot beyond description. These modern refrigerators called suns and starts are only cold-storage remnants of celestial history. This something was squeezed to a solid. It broke off in shells—each shell forming a series long or short. Each shell stretched its elbows as it tore way from the parent mole, and so we find the remarkable order of varying atomic volume, with regularly increasing weight. The dream is so vivid—it wakes us to reality—but the echo of the dream is true all the same. Some day modern science will seriously and soberly consider this new aspirant for recognition in the history of evolution. The atom is waiting to tell his story to the chemical Lamarck. or Darwin, who has the ear to hear.

May the inconsistencies and omissions in the Periodic Sequence grow—and they are many—till the very gaps shall force out the reluctant confession. Confusion in atomic-weight order, confusion in rare earth identification and fractioning, confusion in allotropic form, confusion in argonoid element, in helium radiation, and in electron emanation, impossible distribution of atomic-weight, missing elements in one place, superfluous twins and triplets in others—it all means something. The story of the elements is yet to be written; indeed, carbon is the only one that has thus far accumulated very much of a chemistry. But when it shall be written —this new chapter of atomic birth and growth—men will give thanks for another page in the old Nature story which is never old.—*Engineering and Mining Journal.*

Stated Meeting, held Thursday, February 16, 1905.

On the Chemistry of Wool.

By Dr. J. Merritt Matthews,

Philadelphia Textile School, Lecturer on the Chemistry of Textiles and Pottery, Franklin Institute.

Although wool, and the closely related hair fabrics in general, play such an important part in our social and commercial economy, it is surprising to find that so little scientific work has been done by chemists in connection with the chemical constitution and properties of this important raw material which furnishes the basis of such a large number of industries. It is probably because wool is one of the commonplace materials of everyday life that the chemist passes it by and goes in search of some unheard of and unusable substance to which he may devote his labors of original research. We are, in fact, less acquainted, in a chemical sense, with some of the most commonplace substances of daily life than with many of the rare and less useful substances. The microscopic eye of the scientist is liable to pass by the large bodies near at hand and fix its attention on something far beyond the ken of common things.

In a study of the chemical constitution of the wool fibre, at the very outset a distinction must be drawn between the raw fibre as it occurs in the fleece and the purified fibre as it is used for purposes of manufacture. The fleece, as it comes from the back of the sheep, contains many other substances besides the fibre proper. In the first place, a considerable though varying amount of miscellaneous foreign matter and dirt is always associated with the fibre. This amount may vary from five to twenty-five per cent. of the weight of the fleece. Apart from this material, however, there is always associated with the fibre in a natural manner a large amount of grease, together with the residue resulting from the dried-up perspiration from the animal. The greasy matter, known as wool-fat, is a natural excretion from the sebaceous glands of the skin located around the hair-root of the fibre. The function of this greasy matter

is to prevent the fibres from becoming matted together in the fleece by surrounding them with a rather thick layer of soft fatty substance. In other words, the wool-fat is really a product closely related to the fibre itself, and is a physiological concomitant of its growth. This fat, however, does not in any sense form an integral part of the structure of the fibre, being merely an external coating on its surface and its removal therefrom, which takes place in the process of wool-scouring, does not in any manner affect the physical or chemical properties of the fibre. The dried-up perspiration, or so-called "suint," which also occurs in rather large amount in the wool fibre, differs from the wool-fat in that it is not in any special manner related physiologically with the growth of the fibre. It is merely derived from the perspiration naturally excreted by the sudorific glands in the skin, and which, by reason of the heavy layer of wool on the animal, has no chance of being removed except by evaporation, which of course, leaves within the fleece all the non-volatile solid constituents occurring in the perspiration. This dried-up residue is usually more or less mechanically held by the greasy matter coating the fibre, and is removed together with the latter in the scouring of the wool. The suint is distinguished from the wool-fat in that it is soluble in water, and consists for the most part of potassium salts of various organic acids. The wool-fat is chiefly composed of cholesterol (which is a monatomic alcohol having a high content of carbon atoms) and its related substances. The amount of actual grease present in the raw fleece of the sheep varies from eight to twelve per cent. while the amount of dried-up perspiration varies from fifteen to thirty per cent. The wide limits of variation in these substances are caused by difference in the breed of the sheep, difference in climatic conditons, manner in which the sheep are reared, etc. Taking all the materials existing in the raw fleece into consideration, we will find that the actual amount of fibre present varies from fifty to twenty per cent, with probably an average of thirty-five per cent. for the general grades of wool.

Coming now to a consideration of the fibre proper, we will discuss its general chemical behavior as at present determined. In the first place, wool belongs to the general class of proteoid substances, and is closely related, if not in fact almost identical

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in composition with, the various skin tissues, including feathers, hair, horn, and leather. In other words, it is chemically related to gelatin and albumin. It is not, however, soluble in water, nor the ordinary solvents, although when heated for some time with water under pressure it is gradually decomposed and dissolved. In common with other albuminous substances, wool is evidently an amido-acid. The fact is deduced from many considerations: in the first place, ammonia is to be found among the products of the destructive distillation of wool; again, wool is rather easily hydrolysed by the action of dilute alkaline solutions; also, wool readily combines with acids, and even on boiling with dilute sulphuric acid it is possible to find considerable traces of ammonium sulphate in the solution. Further than this, the presence of an amido group in the wool fibre is strongly evidenced by the fact that on treating wool with an acid solution of nitrous acid and afterwards with a phenolic body, certain well defined colors are obtained analogous to the bodies produced by this same diazotising reaction on ordinary aromatic amines. This method of applying the diazo reaction to wool is interesting, and by the use of a variety of phenolic and amido bodies as developers for the diazo compound of the wool a variety of colors may be produced on the fabric. In such instances the wool acts as its own dyestuff, or rather, it acts as the material from which the dyestuff itself is made.

The presence of an amido group in the wool fibre is also evidenced in the many ways in which wool exhibits its well-defined basic properties. In the first place, wool combines with and neutralizes a considerable amount of acid; for instance, if wool be boiled in a solution of sulphuric acid for some time, and then thoroughly washed until the wash waters are perfectly neutral, by a quantitative determination, the amount of acid neutralized by the wool may be readily ascertained. In this manner it is possible to obtain what may be termed the "coefficient of acidity" of wool. This is a number representing the amount of caustic potash, expressed in milligrams, neutralized by one gram of wool. This coefficient of acidity for wool, together with other related albuminoids, may be given as follows:

Wool = 57; Silk = 143; Albumin = 20.9; Gelatin = 28.4.

The basic nature of the wool fibre is furthermore evidenced

by the readiness with which it combines with acid dyestuffs, in which reaction it appears that there really exists some sort of chemical combination between the acid constituent of the dyestuff and some constituent in the wool.

In common with other amido acids, wool also exhibits in some degree the properties of an acid. It will absorb alkalies from solution and effect a partial neutralization of them. Owing to the fact, however, that it is not possible to determine with any degree of exactness the amount of alkali actually neutralized by the acid component of the fibre, it is not possible to furnish a coefficient of alkalinity for wool corresponding to the coefficient of acidity. This is caused by the fact that alkalies affect a decomposition of wool before the acid nature of the fibre is completely saturated. The fact, however, that when wool is treated in the cold with concentrated solutions of caustic potash there is a considerable absorption of the alkali by the fibre which cannot afterwards be removed completely by washing, would indicate a neutralization of the alkali by some acid component of the fibre. It has also been found that wool which has been thus treated has a lessened attraction for the general class of basic dyestuffs. In this connection, it may also be said, from the very fact that wool does exhibit in its normal condition, a considerable affinity for the basic colors, would be an indication of its containing an acid group in its constitution.

It is hardly probable that the wool fibre as a whole can be considered as a homogeneous chemical compound. I am led to this conclusion not only by a study of the varying chemical behavior of wool towards many reagents, but also by a consideration of its physical structure. In the latter respect the fibre is composed of three well-defined parts: an external sheath of flattened and hardened cells, an under layer of long fibrous cells which make up the major portion of the fibre, and finally a central layer of round medullary cells. From the very fact that these different portions of the fibre possess separate structures and functions, it would be reasonable to expect to find them possessing difference of chemical constitution. As it is an exceedingly difficult matter to satisfactorily separate from one another these different portions of the fibre for purposes of chemical analysis and study, it is not possible to state just what these chemical differences may be. I have found,

however, in the study of the action of alkalies on the wool fibre, that the external layer of cells, which furnishes the scales on the surface of the fibre, appears to be attacked in a somewhat different manner from the rest of the fibre; also in the action of the majority of dyestuffs on wool, I have found that these external cells are generally not dyed like the inner layers of cells. Although I am aware that these differences may be due more or less to differences in the physical structure of the cells, nevertheless, they are more likely to be due to the difference in chemical composition.

Another consideration which leads me to the conclusion that wool is not a homogeneous chemical compound is that by the action of alkalies a certain amount of one of its components, sulphur, may be removed without any apparent physical disintegration of the structure of the fibre. Also, in different qualities and kinds of wool, the percentage of sulphur present in the fibre is quite a varying factor. Whether this chemical difference is located in the substance of the different characters of cells to be met with in wool, or whether it is due to differences in the composition of the cell-wall as compared with the contents of the cells, we do not at present know, as it has not been possible as yet to satisfactorily separate the substance of the cell-wall from its contents. The chief hope of any scientific work in this direction lies in a study of the micro-chemical reactions of wool with various reagents.

ACCIDENTS ON AMERICAN RAILWAYS

Are attracting so much attention just now that it is particularly interesting to review the figures given in the report of the Interstate Commerce Commission for the year ending June 30, 1904. There were 43,266 employes injured and 3,367 killed in 1904, as compared with 33,711 injured and 2,516 killed in 1902. The figures for 1903 are intermediate between those for 1902 and 1904. In 1904 there were 8,077 passengers injured and 321 killed; in 1902, 6,089 injured and 303 killed; in 1903 there were 6,973 injured and 321 killed. The increase in the number of deaths of passengers in train accidents in 1904 compared with 1903 is 64½ per cent. There were ten unusually disastrous accidents during the year. The number of deaths resulting from these accidents, eight of which were collisions, is about 23 per cent. of the total number killed in all the train accidents of the year, which comprise over 6,000 collisions and 4,800 derailments. Although there has been earnest discussion of the subject in the public press, it is noticeable that the very magnitude of the question involved appears to have produced some confusion, and in the multitude of causes assigned the real question in many cases has been lost sight of. The paramount requirement, as pointed out in the last annual report, is an effective measure for the prevention of collisions.

Book Notices.

A Practical Method of Adjusting a Modern Gun and Determining its Errors in Azimuth, Elevation and Vertically as well as the Errors of the Telescopic Sight. By Otto von Gelden, M. Am. Soc. C. E., Civil Engineer. (Circular No. 4. 12 mo. paper, 21 pages.) Headquarters Pacific Division, San Francisco, Cal. Published by command of Major-General MacArthur, Washington. Government Print. 1904.

This pamphlet describes in detail a method of adjusting and calibrating the training and elevation arcs of a modern sea-coast gun.

The author points out the similarity between the motions of the gun and those of a transit and describes the method of training the gun in azimuth to correspond with the setting of the transit and comparing the readings. From the readings obtained from a number of stations an error curve of the training-arc angles is plotted. The elevation-arc is tested for one position only from each station.

The description is very clearly written and should prove of value to those interested in artillery engineering. L. E. P.

Le Calcul Simplifié par les Procédés Mechanique et Graphique. Historie et description sommaire des instruments et machines á calculer, table, abaques et nomogrammes. By Maurice d'Ocagne, Ingenieur des Ponts et Chaussées, Professeur á l'Ecole des Ponts et Chaussées, Répétiteur á l'Ecole Polytechnique. Second Edition, entirely reset and considerably enlarged. 8vo, cloth, 225 pages, 73 figures. Gauthier-Villars, Paris, 1905. (Price, 5 francs.)

The literature of calculating machines and other devices for lessening the labor of numerical computation is not in an easily accessible form and the work before us embracing, as it does, in small compass a history and concise but not too brief description of the more important forms of such instruments brings within easy reach a comprehensive and up-to-date view of the entire subject.

The first three chapters, comprising 128 pages, are devoted to mechanically operated devices, from the most simple types, in logical order, to elaborate and complex machines whose principles and important details of mechanism are described at considerable length.

The remainder of the work treats of graphic computation by geometric construction, by diagrams in rectangular coördinates, by diagrams in distorted coördinates of which the well known system of logarithmic coördinates is a special case and, lastly, by a system of representing in one plane the simultaneous values of three-variable expressions by the use of graduated lines. This last feature is of particular interest in its application to technical work, but to one unacquainted with the development of the process employed the description is not sufficiently full. The author's aim, however, appears to present this part of the subject in outline only, referring to his Traité de Nomographie for a full discussion.

The large number of foot-notes of bibliographic references is a particularly commendable feature. L. E. P.

Chemical Analysis for Glassmakers. Containing methods of analysis for clays and other silicates, which will be found useful for the pottery industry. By Edward C. Uhlig, B.S., M.A.C.S., etc. (8vo, pp. 136.) Pittsburgh: Kaufmann & Gauding, N. D. (Price, $5.00.)

The author of the above-entitled book has endeavored to explain to those engaged practically in glassmaking the essential principles of chemical analysis, to enable them to exercise a scientific supervision of their works. It should prove a useful hand-book for those for whom it is intended. W.

Text-Book of Organic Chemistry. By Henry Leffmann, M.D., and Charles H. LaWall, Ph. G., (with illustrations and experiments.) Philadelphia: P. Blakeston's Son & Co. 1904. (Price, $1.00 net.)

The authors present in this volume in exceedingly compact form a compendium of organic chemistry covering those features of the science which will be likely to prove most useful in its applications to pharmacy, medicine and the industries. W.

Laboratory and Factory Tests in Electrical Engineering. By George F. Sever, Adj. Prof. Electrical Engineering, Columbia University, and Fitzhugh Townsend, Tutor in Electrical Engineering, Columbia University. (8vo, pp. xii + 236.) New York: D. Van Nostrand Co. 1904. (Price, $2.50 net.)

This book represents substantially the course of laboratory practice required in the Electrical Engineering Course at Columbia University. It will be found helpful, not only to students of electrical engineering, but also to the great number of those engaged in the higher branches of the electrical profession. W.

Sections.

CHEMICAL SECTION.—A joint meeting of the Chemical Section and the Philadelphia Branch of the American Electro-Chemical Society was held this evening, Thursday, January 19th, at 8 o'clock. Present, 42 members and visitors. In the absence of the President, Prof. G. A. Hoadley was called to the chair.

The evening was devoted to the reading and discussion of a paper by Prof. Wilder D. Bancroft, of Cornell University, on "The Chemistry of Electro-Plating.

The speaker illustrated his remarks with the aid of specimens of plating with various metals, lantern slides and photo-micrographs, exhibiting differences in structure of the deposited metal, due to changes in the chemical constitution of the bath and physical conditions of deposition.

The subject was freely debated by Messrs. Carl Hering and Charles J. Reed, Drs. H. F. Keller and Wm. H. Wahl, Prof. George A. Hoadley and the author.

The thanks of the meeting were tendered to Professor Bancroft, and the session was adjourned.

WM. H. WAHL,
Secretary pro tem.

Stated meeting held Thursday, February 16th, 8 P.M. Dr. E. Goldsmith in the chair. Present, 15 members.

Mr. John Howard Graham, Central High School, Philadelphia, was introduced by the Chairman, and read a communication on "The Determination of Sulphur in Iron Ores."

The paper was discussed by Dr. W. J. Williams, Dr. H. F. Keller, Dr. E. Goldsmith and the author.

The speaker was given a vote of thanks for his interesting communication.

In the absence of Dr. J. Merritt Matthews, his paper on "The Chemistry of Wool," was read by the Secretary. Discussion was deferred.

Both papers were referred for publication.

A resolution was passed requesting the Committee on Sectional Arrangements to put to a vote of the members the question of consolidating the Chemical and Physical Sections, and the annual election of officers was postponed until the result of the vote had been ascertained.

WM. H. WAHL,
Secretary pro tem.

MECHANICAL AND ENGINEERING SECTION.—*Stated Meeting*, held Thursday, January 26, 8 P.M. Mr. Charles Day in the chair.

Present, 143 members and visitors.

The following officers were elected: President, Charles Day; Vice-Presidents, H. W. Spangler, Kern Dodge; Secretary, D. Eppelsheimer, Jr.; Conservator, Wm. H. Wahl.

The meeting was devoted to a discussion of the subject of "The Steam Turbine," and was opened by Prof. Spangler. The following persons participated: Prof. L. C. Lœwenstein, Lehigh University; Mr. J. A. Lafore (representing the De Laval Steam Turbine Company); Mr. Richard L. Rice (representing the General Electric Company); Mr. J. H. Macalpine, W. C. L. Eglin and Francis Head and others.

The Chairman tendered the thanks of the meeting to the speakers of the evening and adjourned the session.

WM. H. WAHL,
Secretary pro tem.

Stated meeting held Thursday, March 2d, 8 o'clock. Mr. James Christie in the chair. Present, 84 members and visitors.

The first communication of the evening was presented by Prof. W. F. M. Goss, of Purdue University, Lafayette, Ind., on "The Application of Superheated Steam in Locomotive Service," which the speaker illustrated by the exhibition of a series of lantern photographs. The paper was freely discussed, and is referred for publication.

Mr. G. H. Mumford, of the Tabor Mfg. Co., Philadelphia, read the second communication, on "Foundry Moulding Machines," which was likewise illustrated.

The speakers were given the thanks of the meeting, and the session was adjourned.

WM. H. WAHL,
Secretary pro tem.